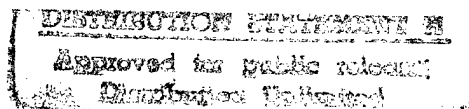

STRESS AND DECISION-MAKING
IN
TRAUMA PATIENT RESUSCITATION

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Contents

1	Introduction	12
2	Background and Research Questions	14
2.1	Impact of Stress on Performance	14
2.2	Measurement of Stress	15
2.3	Existing Framework for Modeling Cognitive Activities	16
2.3.1	Explicit Modeling	16
2.3.2	Abstraction Methodology	17
2.4	Types of Cognitive Analysis	17
2.5	Modeling Decisionmaking	18
2.5.1	Normative Decision Models	18
2.5.2	Algorithmic Decisions	19
2.5.3	Descriptive Decision Making Models	20
2.6	Fixation Errors	21
2.7	Team Performance under Stress	22
2.8	Studies Using Video Recording in the Real Environment	23
2.9	Socio-Legal Issues of Videotaping in Real Environments	24
2.10	Video Analysis	24
2.11	A Framework for Studying Decisionmaking under Stress	25
3	Description of Trauma Patient Resuscitation	32
3.1	Trauma Patient Resuscitation	32
3.2	Characterization of the Domain	33
3.3	Tasks of Airway Management	33
3.4	Participants	37
4	Acquisition of Audio-Video-Data	38
4.1	Audio-Video Acquisition System	38

4.2	Overview of Video Acquisition System Network (VASNET)	38
4.3	Strengths and Limitations of VASNET	40
5	Data Collection in the Real Environment	44
5.1	Consent and Confidentiality	44
5.2	Recording of Activities during Resuscitation	45
5.3	Companion Data Collection	45
5.4	Fatigue Measurement	46
5.5	Post-Trauma Questionnaire	48
6	Video Analysis	50
6.1	Introduction	50
6.2	The Environment for Video Analysis (VINA)	50
6.3	Overall Methodologies of Video Analysis	51
6.3.1	Intubation Analysis	51
6.3.2	Commentaries	54
6.3.3	Perceived Subjective Stress Ratings	54
6.3.4	Communication Analysis	56
6.3.5	Categories of Data Available	58
7	Incidents Captured by Video versus Self-reporting	61
7.0.6	Methods	62
7.0.7	Results	63
7.0.8	Discussion	65
8	Systems Factors Influencing Decisionmaking	68
8.1	Workplace Layout	68
8.1.1	Introduction	68
8.1.2	Experiment 1: Initial Design	70
8.1.3	Experiment 2: Layout Efficiency	72
8.1.4	Experiment 3: Satisfaction Measure	73
8.1.5	Discussion	75
8.2	Auditory alarms	78
8.2.1	Method	78
8.2.2	Results	78
8.2.3	Discussion	82

9 Performance Metrics	83
9.1 Task performance: Are all the steps equally important?	83
9.1.1 Task omissions	83
9.2 Comparing Performance of Experts with That of Non-Experts	85
9.3 Comparison of Elective and Emergency Tracheal Intubation	87
9.4 Discussion	89
10 Measurement and Prediction of Stress	92
10.1 Post-Case Self-Reports of Stress	92
10.2 Determinants of Trauma Anesthesiologists' Perceptions of the Difficulty and Stressfulness of a Case	93
10.2.1 Introduction	93
10.2.2 Methods	93
10.2.3 Data Analysis	94
10.2.4 Results	96
10.3 Measurement of Perceived Stress	97
10.3.1 Characterization of Collected Data on Stress	97
10.3.2 Assessment of Interrater Reliability	97
10.3.3 Factors of Perceived Stress	97
10.3.4 Correlations Among the Measured Variables	101
10.4 Regression Analysis	101
10.4.1 Temporal Profiles of Stress Ratings Over Time	103
10.5 Discussions	108
10.6 Measurement of Physiologic Responses to Stress	109
10.6.1 Discussion	112
11 Decisionmaking under Stress	113
11.1 Fixation Errors	113
11.1.1 The Case	113
11.1.2 The Evolution of Fixation Errors	113
11.1.3 Analysis of Fixation Errors	116
11.1.4 Discussion	117
11.2 Stress and Performance	118
11.2.1 Method	120
11.2.2 Results	120
11.2.3 Discussion	120

11.3 Video Analysis of Two Emergency Tracheal Intubations	122
11.3.1 Introduction	122
11.3.2 Methods and Materials	122
11.3.3 Results	123
11.3.4 Discussion	125
11.4 Prolonged Esophageal Intubation	130
11.4.1 Methods and Materials	130
11.4.2 Discussion	133
11.4.3 Conclusions	136
12 Team Performance under Stress	142
12.1 Task Complexity and Team Coordination	142
12.1.1 Introduction	142
12.1.2 Extraction of Data for Studying Task Complexity	143
12.1.3 Analysis	144
12.2 Results	144
12.3 Components of Task Complexity	144
12.4 Implications for Task Complexity in Team Environments	148
12.4.1 Coping with Complexity	150
12.5 Conclusions	151
13 Team Coordination Strategies	152
13.1 Method and Materials	152
13.1.1 Data Processing and Video Analysis	152
13.2 Strategies of Coordination	152
13.2.1 Task Coordination	154
13.2.2 Information Flow	155
13.3 Coordination Breakdowns	155
13.3.1 Pressure to Seek Alternative Solutions	157
13.3.2 Initiation of Unexpected, Non-Routine Procedures	157
13.3.3 Diffusion in Responsibility	157
13.3.4 Summary of Strategies for Team Coordination and types of coordi- nation breakdowns	158
13.4 Discussions	158
13.5 Conclusions	160
14 Models of Decisionmaking	162

14.1 The Importance of Clinical Cues	162
14.1.1 Introduction	162
14.2 Decision Trees	166
15 Future Applications	171
15.1 Telemedicine	171
15.2 Evaluation of Performance and Procedures	172
16 Summary	173
16.1 Implication for Future Research on Team Performance and Stress	175
16.2 Future application of the results and products of this research	175
16.3 Conclusions	176
References	177
Appendix I: Questionnaires	189
Appendix II: Coding System for Verbal Communications and Activities	205
Appendix III: Case Example	211
Appendix IV: Database Description	243
Appendix V: List of Publications	244
Appendix VI: Glossary	247

List of Tables

6.1 Task list for tracheal intubation	55
6.2 Stressors used in the subjective ratings	60
8.1 Principles of Layout (Sanders & McCormick, 1987)	71
8.2 The four best and worst rated areas of the TRU bay divided by specialty . .	75
9.1 Importance scores for tasks in intubation	84
9.2 Task durations of intubation events	91
10.1 Stress measured by Post Trauma Questionnaire	95
10.2 Result 1 of principal components analysis of Stressors	95
10.3 Result 2 of principal components analysis	95
10.4 Result 3 of principal components analysis of Fatigue Stressors	98
10.5 Result 4 of principal components analysis identifies the PTQ items and the factors identified in Table10.4	98
10.6 Result 5 of principal components analysis of Injury Severity	98
10.7 Result 6 of principal components analysis identifies the questionnaire (PTQ) items related to the factor identified in Table10.6	98
10.8 Result 7 of principal components analysis	99
10.9 Result 8 of principal components analysis	99
10.10The numbers of data points of the collected subjective stress ratings	100
10.11Intraclass correlation coefficients	102
10.12Correlation matrix for the subjective stress ratings	102
10.13Results of principal component analysis.	102
10.14Results of multiple linear regression	104
10.15Comparison participant versus neutral raters	104
11.1 Pearson r matrix between stress ratings and task omissions and decision- making errors	139
11.2 Major events and elapsed time since admission during resuscitation of Case 1140	

11.3 Major events and elapsed time since admission during resuscitation of Case 2141	
14.1 Evaluation parameters, and frequency of completion of simulator tasks among ten participants	165

List of Figures

2.1	Implicit cognitive analysis	26
2.2	Exemplary analysis method	27
2.3	Example of decision tree	28
2.4	Rasmussen's decision ladder	29
2.5	The recognition-primed decision model by Klein (1989)	30
2.6	A framework for studying decisionmaking under stress.	31
3.1	Means-end representation of the domain of trauma patient resuscitation . .	34
3.2	Admitting area layout	34
3.3	Tracheal intubation illustrated by photo and drawing	36
4.1	Video image of trauma patient resuscitation	39
4.2	Video Acquisition System Network (VASNET) signal flowchart	41
4.3	VASNET network structure	42
5.1	Practice Synwork scores of five subjects	47
5.2	Mean and standard errors of Synwork scores for day and night shifts	47
6.1	VINA: An environment for video analysis	52
6.2	Overview of database contents and analyses from video data	53
8.1	The current Trauma Resuscitation Unit bay layout	71
8.2	New bay layout	74
8.3	Comparison of subjective satisfaction scores before and after update	74
8.4	The Workspace Appropriateness score.	77
8.5	The duration of auditory alarms from ventilators and end-tidal CO2/pulse oximeter monitor	79
8.6	The occurrences of false alarms	80
8.7	The rate of silenced, false, and missed alarms	81
9.1	Task omission, before and after weighting of importance	86

9.2	Comparison of duration of accomplishing intubation	86
9.3	Comparison of number of attempts to accomplish intubation	88
9.4	Percentage of task completed before, during and after intubation	88
10.1	Comparison of temporal stress profiles with different alignment points	105
10.2	Task urgency and stress temporal profile	106
10.3	Temporal profile of seven measured items of stress.	107
10.4	Electrocardiograms of an anesthesiologist during elective and emergency intubations	110
10.5	Heart rate and blood pressure of an anesthesiologist from an ambulatory monitor	111
11.1	Case event overview: esophageal intubation	114
11.2	Prolonging the window of opportunity through pre-oxygenation	121
11.3	Correlational relationship between performance and stress ratings	121
11.4	Recommended task communication algorithm for airway management	138
12.1	Comparison of two types of intubation: high versus low urgency	145
12.2	Monitoring information available during low and high urgency intubation . .	146
13.1	Sample analysis results of verbal communications	153
13.2	Flow patterns of verbal communication	156
13.3	Coordination breakdowns when team encountering unexpected obstacle(s) . .	159
13.4	Coordination breakdown pattern: change in plans	159
14.1	Ideal and actual action sequence in the real case	163
14.2	Comparison of paths of action sequences taken in real events and in simulated events	165
14.3	Differential diagnoses made by simulator participants after endobronchial intubation	168
14.4	Hypertension decision tree	169
14.5	Patient vital signs and decisionmaking	170
I.1	Post Trauma Questionnaire (PTQ)	190
I.2	Intubation Analysis Questionnaire (IA)	192
I.3	Stressor Collection Form	203
I.4	Recall Questionnaire	204
II.1	Coding System for Verbal Communications and Activities	206
III.1	Transcriptions of the verbal communication and codings for the example case	212

III.2	Transcriptions of the commentaries by the attending anesthesiologist who participated in the care in the example case	220
III.3	Transcriptions of the commentaries by an anesthesiologist who did not participate in the care in the example case	223
III.4	Patient admission record for the example case	227
III.5	Intraoperative anesthesia record for the example case	228
III.6	Laboratory analysis, hematology, and biochemistry data for the example case	230
III.7	Operative and discharge summary for the example case	237
III.8	Fluid infusion records for the example case	241

Chapter 1

Introduction

Decisionmaking tasks occur when courses of action need to be determined. Investigations of past accidents in industrial and military activities have often concluded or suggested that the performance failure of the human element in decision-making is a primary cause (e.g., Perrow, 1984; Reason, 1990; Pew *et al.*, 1981). However, as pointed out by the contributors in a recent volume on decisionmaking (Klein *et al.*, 1993), researchers (e.g., Hammond, 1986; Sinnott, 1989) as well as practitioners have become dissatisfied with the ways in which human decision-making has been studied. The primary criticism has been that classic approaches to decision-making studies rely almost exclusively on laboratory experiments, using static and simplistic tasks and individual novice subjects. In comparison, in reality people often work in environments

- that are *fast-changing, complex and uncertain*;
- in which the performance in decision-making carries *high stakes*; and
- in which critical decisions have to be made under *extreme time pressures*.
- in which decisions are made and carried out collectively by multiple individuals in a team.

These characteristics of many work environments call for studies in *naturalistic* settings, in order to understand properties of human decision-making under stress in real life. The ultimate goals of these types of studies are to provide effective decision aids and training programs for those who work in complex, dynamic civil and military environments.

The project reported here was initiated to study decisionmaking under stress in real-environments. A primary objective of it was to ensure simultaneously in one study setting (1) high frequency of occurrence of real-life stressful, life-threatening situations and (2) data-rich recording of events and activities. This objective was important for naturalistic studies because in real environments, high-stress, life-threatening events are often rare and unpredictable; researchers often have inadequacy of documentation and records.

Over the course of the project, we

- Developed a video-audio data acquisition system which was used successfully in the acquisition of multi-media data in a real environment;
- Developed data collection methodologies that collected audio-video recordings, retrospective questionnaires, subjective reviews, performance evaluations and

stress measurements

- Developed a set of video analysis tools to measure communications and task performance
- Developed a software tool that greatly enhances the efficiency of video analysis
- Collected a sizable database which contained multi-media data of performance in a real, stressful environment
- Performed in-depth analysis of a number of cases in terms of the task variables and cognitive processes that influence successful skilled performance and cognitive decision-making in a real situation in which life and death decisions are being made.

In this report, we will identify the major efforts in the study of decision under stress. The chapters are outlined below:

- Chapters 2 and 3 describe existing literature and background information of trauma patient resuscitation.
- Chapters 4 and 5 describe the data collection using video recording in work settings.
- Chapters 6 through 9 describe video analysis methodologies.
- Chapters 10 through 12 describe results of stress measurement and its impact on decisionmaking and team performance.
- Chapter 13 describes several models of decisionmaking.

The majority of the results reported here were from analyses while data collection was on-going. Because of this, the sample sizes used in each analysis were different.

Chapter 2

Background and Research Questions

2.1 Impact of Stress on Performance

Stress has been a topic that receives extensive attention in the literature, much of which deals with stress of occupational and social origin and its long-term impact (e.g. Goldberger & Breznitz, 1982).

Under laboratory condition, Weltman et al (1971) used a dual task paradigm to contrast the performance of stress and control groups. In the experiment the subjects were asked to perform a central and a peripheral task. They found that although the performance of central task was comparable in stress and non-stress groups, the peripheral task was significantly degraded for the stressed group. Measurable reaction to stress, such as increases in heart rate was found in the stress group.

Berkun (1964) used simulation to impose a stressful experience onto soldiers, and tested subjects' ability to follow procedures under stress. He found that the degradation of performance was less for soldiers with greater experience. In other words, the negative effects of stress was reduced by higher skill and ability. Similarly, Eysenck (1976) found that well-learned or over-learned procedures were less prone to the effect of stress. Lazarus and Ericksen (1952) also found that experience helped in reducing the negative effects of stress.

Through reviewing previous studies and his own, Fuchs (1962) proposed the hypothesis explaining why experience could reduce the negative effects of stress. In the hypothesis, one tends to revert to earlier and more compatible response patterns when they conflict with incompatible patterns. Fuchs further proposed that under stress there is a tendency to rely on immediate feedback in the perceptual range, thus prone to cognitive tunneling effect of stress. The cognitive tunneling effect of stress manifested in a study by Keinan and Freidland (1984). In their study, it was found that in decision making tasks, physical threat as a stressor reduced the scanning of alternatives.

Using the time-to-jump as a stressor, Simonov et al (1977) studied how paratroopers performed in a signal detection task. They found that the subjects had increase false-alarm rates when they were close to the time to jump. According to the signal

detection theory, the stress changed decision criterion and lowered the threshold of what counted as a signal.

These studies all concluded the negative impact of stress on performance in various tasks. They also showed the beneficiary effects of skills and training when performing under stress. However, the relationship between performance and stress is not linear. Easterbrook (1959) proposed that when stress was moderate, the effect of stress may actually help the performance by "energizing" the subjects and forcing subjects to focus; when stress was excessive, the effect of stress is usually negative.

Janis and Mann (1977) made a similar proposal, in which the effect of stress would result two types of outcomes: when stress is moderate, there is a healthy level of vigilance that facilitates thorough search, appraisal, and contingency planning; when stress is excessive, people tend to be hypervigilant, this results in incomplete search, appraisal, and contingency planning.

2.2 Measurement of Stress

The measurement of stress has been a major challenge in the investigation of stress. Physiological, subjective, and task related measures have been used to quantify stress.

A number of studies manipulated certain aspects of tasks to reflect the level of stress. In these studies, stress is not measured but rather assumed. Examples of such manipulations include the time allowed to complete a given task (Coury & Boulette, 1992) and the level of the threat of electric shocks (Keinan & Freidland, 1987).

Measurement of physiological responses to stress were used to study performance under stress, such as restlessness (Galinsky *et al.*, 1993), metabolism wastes (Burton *et al.*, 1977) and speech patterns (Doherty, 1991).

In many settings people are under variable levels of stress, which can be induced by changing environmental noise, the fluctuation in task workloads, or the anxiety caused by one's own errors. It is important to continually measure stress in order to see the dynamics of stress in such circumstances. However, stress is typically measured and/or manipulated over *complete* study sessions.

Several reported studies attempted to measure *dynamic* changes of stress levels over time. Simonov *et al.* (1977) continually measured electrocardiogram (ECG) parameters (lengths of R-R intervals and amplitudes of T-waves) as indications of anxiety. Brenner, Doherty, and Shipp (1994) used speech characteristics (*e.g.*, fundamental speech frequency) during stressful situations to measure workload demand. Hart and Hauser (1987) had subjects fill in questionnaires at seven predefined task points (over the span of an average of 7 hours) to measure stress.

Although some physiological measures (such as ECG parameters, heart rate, and blood pressure) can be used to continually record physiological reactions to stress, such measures are difficult to deploy in many settings. Physiological measures also suffer from the problem of lack of identification of stress sources. In comparison to physiological measures, subjective measures of stress have the advantages that (1) they provide straightforward measures of stress, (2) they are potentially diagnostic in determining the sources of stress, (3) they can be obtained after the performance session to avoid task

interference. (4) they are versatile in terms of the variables that can be measured, and (5) they are relatively simple to obtain. However, since traditionally only one set of subjective ratings is obtained for a complete session, subjective ratings of stress can be insensitive to *dynamic* changes in stress during a task.

2.3 Existing Framework for Modeling Cognitive Activities

Recent studies of cognitive activities in work settings can be traced back to the early age of process control research (*e.g.*, those reported in Edwards & Lees, 1974), as people were starting to be concerned more and more about intangible thought processes, as opposed to directly measurable physical process. The cognitive mechanisms of human operators were examined by various methodologies, including the experimental approach (such as the "water bath" experiments in Crossman & Cooke, 1962; Moray *et al.*, 1986; Sanderson *et al.*, 1989), simulator approach (*e.g.*, Bainbridge, 1974), and field studies (*e.g.*, Beishon, 1974; Xiao, 1994). Even though the technology for recording behavior increases in sophistication, the challenge confronting researchers remains the same: using *observable* data to infer *mental* processes.

2.3.1 Explicit Modeling

Verbal reports given by studied subjects tend to lend themselves to analysis of underlying cognitive activities. Many studies on cognitive activities were based on verbal data. Carroll and Johnson (1990, pp. 77–83) outlined three types of analysis of verbal data: exploratory, content, and explicit modeling. While exploratory analysis deals exclusively in the semantic domain, content analysis involves categorization and coding. They seem to suggest that explicit modeling is the ultimate goal of protocol analysis: building a computer simulation to account for the protocol data. This series of steps of analyses essentially document what Newell and Simon (1972) have done in their classic studies on human problem solving. "The advantage of the computer simulation is that it forces a level of specificity seldom reached in other ways" (Carroll & Johnson, 1990, p. 81). Along with the gain in specificity, however, comes the price, in the form of limitations on what types of data that one can deal with: studied tasks usually are "(1) fairly short; (2) repetitive; (3) not so highly structured that people simply read materials in order; (4) not so unstructured that responses are idiosyncratic and hard to code; and (5) verbally processed, that is, not based on nonverbal or over learned skills that are inaccessible to consciousness . . ." (Carroll & Johnson, 1990, p. 83).

When confronted with activities in real environment in which complex tasks are carried out, researchers have the problem that verbal reports alone are not usually adequate. On the one hand, verbal reports may be very scarce or inadequately recorded. For example, in the investigation of industrial accidents, there may be no recordings of verbal information. On the other hand, one has to take into account other information, such as physical activities, system logs documenting the changes in the system under control. Thus one of the methodological questions is: *How to integrate information from various sources and to infer with some reliability, the underlying cognitive activities?*

2.3.2 Abstraction Methodology

Hollnagle et al (1981) analyzed incident reports, simulation observations, and verbal protocols during actual start-ups in the domain of power generating plants. An important contribution by Hollnagle et al (1981) is the notion of *abstraction* of the raw data to remove context specifics and *identification* of strategies and performance criteria. The analyzing paradigm promoted by Hollnagle et al (1981) was used in a recent field study (Xiao *et al.*, 1993; Xiao, 1994) in anesthesiology that dealt with verbal data. Similar attempts were made by Pew et al (1981) and Woods (1984). Pew et al (1981) cataloged critical incidents in the nuclear power plant domain and proposed plausible mental information processing models, which were used in evaluation of proposed changes in a plant design. Woods (1984) used the summary information of event-logs to reconstruct the plausible evolution path of actual events, and inferred the associated mental activities.

2.4 Types of Cognitive Analysis

Given the current status of the art, one of the research questions needed to be addressed is a framework for data analysis. Review of literature leads us to classify various types of cognitive analysis into three categories:

Implicit analysis Implicit cognitive analysis (Figure 2.1). presents us with a number of fascinating real-life stories and insightful theories or frameworks. The roles of individual cases are for *illustrating* theories or frameworks.

Previous studies include those on industrial accidents (*e.g.*, Reason, 1990) and on retrospective reports (*e.g.*, Klein, 1989). Partially because of the lack of detailed information on how events evolved, the consumers of such studies cannot examine how the results were derived and whether alternative analyses are possible (as pointed out in Roth *et al.*, 1987; Woods, 1993). The reader either accepts the conclusions, or rejects them all together.

Exemplary analysis Like the implicit analysis, there are large leaps from data to models in exemplary analysis (Figure 2.2). The role of the data in particular cases is eventually for illustration that the proposed model *can* explain the key phenomena. However, because more information about the process of how an event had evolved, the readers are provided with a chance to reinterpret the results (*e.g.*, Xiao *et al.*, 1993).

Often one or two cases attract special attention, partly due to the unusual circumstances surrounding the case, such as the Three Mile Island nuclear accident. Researchers usually have considerable information about the events concerned. For example, there are partial records about the past accidents (*e.g.*, "black-box" for aviation accidents, computer printouts for control rooms) and retrospective accounts of the accidents from witnesses.

This partial information provides researchers with a chance to analyze the event flows at some concrete level, but still there are too many missing parts to do a thorough analysis. A story-line description of incidents was used to reconstruct how events evolved, and

hypotheses or theories were proposed to expose the underlying cognitive activities (such as Woods, 1984). The product of the cognitive analysis is often in the form of a process model: how particular trajectories of cognitive activities came about, either because of some error mechanism (*e.g.*, cognitive tunnel vision or fixation error), or because of the adoption of some strategy (means-end analysis).

Process analysis In laboratory or simulator settings, and in some field settings, extensive recordings of behavior are available, ranging from multiple video sources to detailed retrospective accounts to commentaries on the on-line recordings. The focus of process analysis is to accounting for at least the majority of the on-line data recorded, as done in the classical studies by Newell and Simon (1972).

Usually the researchers have models at hand, often the results of implicit analysis of case data, and the purpose of process analysis is to test the usefulness or generalizability of these models.

Summary It is naturally the case that a number of studies were conducted by combining these types of analysis, either operating on the same set of data, or new data collected as analysis increased its depth. For example, in Beishon's (1974) study of skills in controlling continuous baking ovens, the source of behavioral data used in the study was direct observations with verbal protocol recording. The data were synthesized into an activity chart of the ovenman's behavior. The focus of the behavior modeling was directed at understanding how attention was switched from one activity to another. Beishon summarized his findings in a model which contains a meta-element, called the *executive routine*, to simulate the behavioral pattern that "must follow some kind of cyclic scan procedure . . . on a regular basis" (p. 87) to switch attention among various activities.

2.5 Modeling Decisionmaking

Models of decisionmaking are the starting as well as ending points of research efforts. They provide guidance in the data collection and analysis, while at the same time they synthesize the understanding of how decisions are made and of how decisionmaking could be improved.

2.5.1 Normative Decision Models

When a model of decisionmaking emphasizes how decisions should be made, it is often called normative decision model (National Research Council, 1990). Normative decision process is important to the study of decisionmaking activities in many ways. It enables researchers to focus on individual sub-tasks as specified by a normative process and provides a basis for detecting the need for training and aiding (National Research Council, 1990). Classic decision theories (*e.g.*, Kleinmuntz, 1987) usually start with an assumption of normative decision models and assume the following steps in a decisionmaking task (Einhorn & Hogarth, 1981; Payne *et al.*, 1992):

- Identify all possible courses of actions
- Evaluate options available through predicting their consequences
- Assess the likelihood of each consequence
- Select a course of action through an optimal strategy (*i.e.*, maximizing the expected return)

This normative decision process outlines a paradigm for studying decisionmaking, and many studies have been conducted to investigate human decisionmaking in terms its components in the normative sequence, such as the estimation of probabilities (*e.g.*, Tversky & Kahneman, 1983) and prediction (*e.g.*, Kahneman & Tversky, 1973). Deviations of observed decisionmaking behavior from the normative decision models are often explained by biases (*e.g.*, Tversky & Kahneman, 1974).

Decisionmaking in complex environments are predominantly carried out by experienced practitioners. The direct implication of this observation is that the decision makers will deal mostly with familiar scenarios and will be able to respond to most problems without having to resort to a lengthy or deliberate decisionmaking process. Such flexibility in decisionmaking has not been reflected in current normative models. One of the research questions is thus how to model decisionmaking by experts while at the same time considering the normative aspects of decisionmaking.

2.5.2 Algorithmic Decisions

Decision tasks can be viewed as the provision of a decision on alternatives to be chosen in a given situation. In medical practices, such tasks are often described in algorithmic structures. Sometimes such structures are referred to as trees, even though loops exist in many situations. Decision trees have often been used as a way to represent operational knowledge of a domain. (See Figure 2.3 for an example of the decision trees, which was constructed to complement the current project). Other applications of the concept of a decision tree include the modeling of decision rules (*e.g.*, Gladwin, 1989; Elstein *et al.*, 1978). Decision trees are often used to represent knowledge in a structured and condensed format. There are two types of nodes in decision trees: action and choice points. The normative activities are specified by the order in which choices are made and the order of actions.

One drawback of decision trees, if used directly as descriptive models of decisionmaking, is that activities in a continuous stretch of time have to be examined in order to compare actual performance with decision trees (see Figure 2.3). One also has to assume that the actor actually has to mentally go through all the choice points. In addition, models in the form of a decision tree are inflexible and require numerous hypotheses about the detailed process of mental activities. For example, no chunking is allowed in such models. Problems in modeling arise when considering the fact that skilled workers often can arrive at decisions without going through elaborate decision points. It is difficult to use decision tree-type of models to describe the decisionmaking behavior observed.

Another drawback in the decision trees currently available is that they usually do not refer to clinical cues which can be subtle at times and are often not articulated in textbooks.

2.5.3 Descriptive Decision Making Models

Rasmussen's decision ladder

Rasmussen (1976) analyzed verbal protocols collected during *actual* startups of thermal power stations. Difficulties were met in structuring the protocols, due to the lack of models able to deal with the kinds of behavioral phenomena observed. In an effort to characterize the behavioral patterns observed, Rasmussen represented the field study by first formulating a hypothesized normative sequence of information processing activities (*i.e.*, detect, observe, identify, evaluate, choose, and execute) and the resulting knowledge states of these activities. The actual activity sequences were expressed by short-cuts among the nodes in the normative sequence. The result of this conceptualization is shown in Figure 2.4, which later became known as the "decision-ladder," or the "ladder model" of information processing. According to this framework, the normative sequence of activities and knowledge states involves going up the left leg of the ladder and then down the right leg.

Rasmussen's framework was designed to capture the key characteristics of information processing activities of experienced workers: there were shunting leaps among the normative activities and knowledge states. The observed, actual activities rarely followed the normative sequence (*i.e.*, up and down the two "legs" of the ladder) of activities and knowledge states. Instead, activities or knowledge states were linked together by short-cuts ("rungs" of the ladder) among various nodes in the normative sequence. Related to the decision ladder model, Rasmussen (1983) also provided a widely accepted taxonomy of action control: skill-based, rule-based, and knowledge-based. When behavior is under skill-based control (skill-based behavior), workers perform tasks without much conscious effort, as when an experienced driver drives a car. When behavior is under rule-based control (rule-based behavior), workers match perceived cues or signs with corresponding rules. In both these two types of behavior (skill-based or rule-based), behavior is said to be controlled by procedures, rather than by goals. When behavior is under knowledge-based control (knowledge-based behavior), workers have to evaluate situations, and decide appropriate course of actions consciously. Note that these three types of action control can function *simultaneously*. In a particular situation, one may evaluate the status of the system under control, while at the same time accomplishing a procedure.

Klein's recognition-primed decision model

The work of Klein and his colleagues (Klein *et al.*, 1986; Klein, 1989; Klein & Calderwood, 1991) is probably often attributed for coining the term "naturalistic decisionmaking". Retrospective reports were used exclusively by Klein and his colleagues in their reported studies. Fire-fighters, tank platoon commanders, designers, and managers were asked to report about decision episodes which occurred up to several years ago (Klein, 1989, p. 66). The reports so obtained were coded by independent raters according to whether a decision was made analytically or intuitively, and whether or not concurrent options were evaluated. Results showed the preference of using intuitive, recognizable strategies. Klein (1989) proposed a model of recognition-primed decision (RPD; see Figure 2.5) to account for this preference. The RPD model captured several important characteristics of decision

making under high time pressure: (1) situation assessment often leads to the recall of a single, prototypical response plan (containing goals, expectancies, actions, and critical cues), as opposed to several concurrent, parallel options; (2) mental simulation is used to verify the prototypical plan and modify it if necessary; (3) only if a plan is rejected by mental simulation is another plan examined.

2.6 Fixation Errors

Several previous studies in dynamic environments have noted a unique type of performance failure. This failure is characterized by a fixation, retrospectively speaking, to either a plan or a diagnosis when actions or diagnoses should have been changed due to the changes in the environment. For example, Nagel (1988) describes an airline disaster in which the pilots failed to respond to the abnormal readings and persevered in the take-off procedure, resulting in heavy loss of life. As another example, in a dual-fault experiment, Moray and Rotenberg (1989) found that the subjects tended to concentrate on the first occurring fault while being unable to recognize the second one. Several terms have been used to describe this type of performance failure: "fixation errors" (DeKeyser *et al.*, 1990; Cook & Woods, 1994) and "cognitive lockups" or "cognitive tunnel vision" (Moray & Rotenberg, 1989). Woods (1988) suggests the possibility of errors in dynamic problem-solving worlds when the problem solver fails to see and track changes in the world. Failure to revise is a potent source of errors in forming inappropriate intentions to act.

Gaba (1994) summarized three forms of manifestation of fixation errors:

- This and only this: (1) The persistent failure to revise a diagnosis or plan despite plentiful evidence to the contrary. (2) The available evidence interpreted to fit the initial diagnosis (3) Attention allocated to a minor aspect of a major problem
- Everything but this: (1) The persistent failure to commit to the definitive treatment of a major problem (2) An extended search for information made without ever addressing potentially catastrophic conditions
- Everything's OK: (1) The persistent belief that no problem is occurring in spite of plentiful evidence that it is (2) Abnormalities attributed to artifacts or transients (3) Failure to declare an emergency or accept help when facing a major crisis

In a simulation study, Gaba and DeAnda (1989) examined how subjects diagnosed an endobronchial intubation. Eleven of 19 failed to notice the peak inspiratory pressure, the earliest manifestation of the problem. Three factors believed to contribute to the delay in recognizing the problem: (1) Uncertainty about breath sound symmetry, (2) Assumption of artifact or instrument failure as a cause of falling oxygen saturation, (3) A desire not to interrupt surgery to auscultate the chest or change tube position.

In another simulation study, Schwid and O'Donnell (Schwid & O'Donnell, 1992) used a computer-screen-only simulation to examine diagnosis of an anaphylaxis episode. The fixation error was found to be in the form of inadequately situational assessment before intervention, noticing increased heart rate but not drop in blood pressure, while giving

more anesthetics based on the hypothesis of inadequate anesthetics. They found that if the frequency of blood pressure sampling was increased (from 3 min to 1 min), the proper identification of patient anaphylaxis was higher statistically, ie making less fixation errors.

Reason (1990) describes two types of errors relevant to fixation errors: (1) confirmation bias and (2) overconfidence. Both of these types of errors have the inertia effect of behavior: "In the face of ambiguity, it rapidly favors one available interpretation and is then loath to part with it.... 'A plan is not only a set of directions for later action, it is also a theory concerning the future state of the world. It confers order and reduces anxiety. As such, it strongly resists change, even in the face of fresh information that clearly indicates that the planned actions are unlikely to achieve their objective or that the objective itself is unrealistic.'" (Reason, 1990, p.89-90). Koriati et al (1980) attributed this overconfidence to that people tend to be overconfident in their plans/knowledge. Subsequently, people tend to justify their chosen course of action by focusing on evidence that favors it and by disregarding contradictory signs.

2.7 Team Performance under Stress

Over the past 20 years, a considerable amount of attention has been directed to various aspects of team performance, in particular team communications. Kanki et al (e.g., Kanki et al., 1991) analyzed the communications in aircraft cockpits and concluded that attitude changes were needed to better utilize the resources in managing crisis events. Driskell and Salas (1992) attributed some of the variance in team performance to personality and they found that as stress increased, the concentration of authority in a decisionmaking task also increased.

Team performance is not a unified concept but involves a number of dimensions. A well-known breakdown is taskwork and teamwork (Morgan et al., 1984). Taskwork refers to task performance whereas teamwork refers to how tasks are accomplished by a team. Baker and Salas (1992) proposed a seven-dimension scheme for teamwork performance: giving suggestions or criticisms, cooperation, communication, team spirit and morale, adaptability, coordination, and acceptance of suggestions or criticism.

Clearly, predispositional factors shape how effectively a team functions. One of the predispositional factors is team organization. Morrisette et al (1975) found that redundancy in task division among team members increased a monitoring task performance. Hutchins (1995) observed that even though there was clear task division among the members of a navigation team, overlap of skills was important to the successful functioning of the team. Fleishman and Zaccaro (1992) formalize the team organizational factor in a taxonomy of team functions, which include monitoring of each others' activities and compensation of task workload. One of the questions in team organization is whether or not multiple decision-makers perform better than single decision-maker. Janis (1972) argues that multiple decision-makers can commit "group thinking": a pattern of group behavior characterized by the willingness of taking risks when such risks are not taken if a single decision-maker performs the task.

Rogalski and Samurçay (1993) analyzed team performance in terms of communications. They coded verbal exchanges in several ways: functional purpose, frequency, and direction (i.e. who is talking to whom).

These efforts have laid some ground work in understanding team performance and in measuring team performance. However, very little empirical work in real life environment has been reported on the relationship between team performance and stress. A study of simulated emergency management by Moray *et al.* (1992) showed that even in simulation, the analysis of team performance is difficult because the multiplicity of activities and multitude of communication channels.

2.8 Studies Using Video Recording in the Real Environment

Activity sampling and time and motion studies have been carried out in medical domains since the 1950's. Due to the recent availability of inexpensive high quality video cameras and video cassette recorders, there has been a huge increase in use of videotaping in many different settings (e.g. Weston *et al.*, 1992; Haslam *et al.*, 1985; Russell & Insull, 1979; Hoyt *et al.*, 1988). The advantage of audio videotaping is that it provides a permanent comprehensive source document. This recording can be reviewed repeatedly by many different analysts. The events in complex environments where time pressure and uncertainty predominate can now, with the powerful tool of videotaping, undergo expanded analyses. Since the equipment for recording can be miniaturized, events that previously could not be observed due to limited space, can now be analyzed through viewing of the audio-videotaped events. Information extracted from the videotaped events can be used for system design, identification of training needs, workload analyses, and performance evaluation.

Videotaping has been used to evaluate medical students clinical psychiatric skills (Tardiff *et al.*, 1978; Tardiff, 1981). In family practice, video recordings of examination of the back were used to identify significant variations in clinical examinations. Video was found to provide information not available from other sources, and when used as reinforcement, provide positive feedback (Roland, 1983). Interpersonal skills of surgeons were evaluated by videotaping of a simulated interaction with a patient (Burchard & Rowland-Morin, 1990). The videotape was scored by identifying specific interventions throughout the patient intervention. Still, other uses of videotaping in medicine included the ergonomic analyses of a Trauma Resuscitation Room (Smith *et al.*, 1993). Link analysis was used to design a more efficient layout for the Resuscitation Room. Videotaping has also been used in trauma centers to determine conformity to certain patient management protocols such as Advanced Trauma Life Support (Townsend *et al.*, 1993). In addition, task allocation among team members and decrease in resuscitation time was facilitated using videotape review of trauma patient resuscitation (Hoyt *et al.*, 1988). Quality assurance was another rationale for videotaping of trauma resuscitation (Mann *et al.*, 1994), and video analysis was found to be useful for clinical research. Driscoll and Vincent (1992) used videotaping to organize the trauma team more efficiently. We have shown that videotaping detects quality assurance occurrences that are not identified in self reports such as the anesthesia record and other written records of patient resuscitation (Mackenzie *et al.*, 1996a).

2.9 Socio-Legal Issues of Videotaping in Real Environments

A major challenge with video recording is social acceptance and potential impact on behavior. The primary concern for many people being recorded is possible legal implications of video recording. Formal reports (e.g. Hoyt *et al.*, 1988) and informal communications have documented the difficulties in resolving the legal concern of those who are videotaped.

Several E-mail messages circulated in March, 1996 regarding other Medical Centers' experience with videotaping. These can be summarized as related to Ethics, Risk Management, Medical Records, Legal Counsel, consent and confidentiality, and staff acceptance. Some authors describe horror stories of events recorded on videotape i.e., patient fell off the stretcher during transfer onto a resuscitation gurney and sustained complete flexion and extension of the neck (these authors do not identify whether any permanent injury resulted). In another horror story, the relatives of a recently bereaved family saw the videotape of their mother's resuscitation played on the waiting room television, including the difficult airway management resulting in nose bleeding, cardiac arrest, and 40 minutes of cardiopulmonary resuscitation. From the E-mail message it appears no other centers have maintained a library of videotapes. All of the emergency rooms that used videotaping erased the videotapes shortly after viewing and completion of any analysis.

In one trauma center in Australia, to gain staff acceptance, the video center was labeled and treated as an aid to memory. There was a considerable sentiment that videotaping, if it was erased shortly after the event, was quite acceptable. Some authors made the point that similar confidential information is displayed on a 'white board' prior to patient admission. This white board is erased when the patient is admitted and resuscitation completed. One problem perceived with repeated reviewing of an occurrence is that this mistake would be imprinted in the health care workers minds. Should a medico-legal case arise, every detail of the error would be remembered when time came for a deposition statement.

Due to the nature of consent, the awareness of videotaping can change the very behavior being recorded. So far the impact of videotaping on behavior has been deemed insignificant (e.g. Pringle & Stewart-Evans, 1990).

2.10 Video Analysis

Analysis of video data is labor-intensive. Unlike audio data, which can be readily transcribed, transcription of which is usually enough, video data contain mostly non-verbal information. The work by de Groot (1965) and Ericsson and Simon (1984) lay the foundation of verbal protocol analysis, but, in the analysis of video data, researchers usually focused on non-verbal data and have relatively fewer previous methodological guidelines. Sanderson and Fisher (1994), based on the ideas presented by Tukey (1977), attempted to build a general framework for analyzing data that are indexed by time. They emphasized the usual exploratory nature in analyzing behavioral data, especially those collected in real world. In addition, time-indexed data cover not only transcriptions of verbalization, but also events, transactions, non-verbal communications (e.g. gestures

and facial expressions), and other observations that one can make in the review of video data. Sanderson and Fisher describe the steps in analyzing time-indexed, sequential data by 8 C's: chunking, commenting, coding, connecting, comparing, constraining, converting, and computing. The framework provides a guide to data analysis, yet tools are still needed to increase the efficiency in dealing with video data.

A number of computer systems have been developed in assisting the manipulation and coding of video data. Three of such systems were tested in the current project, one of which was used extensively.

- MacSHAPA (described in Sanderson *et al.*, 1989). This tool has integrated VCR (video cassette recorder) control, annotation, and coding, with post-coding analysis functionality. Currently it is only available in Macintosh platform. It is able to control several major models of VCRs and interface with the time code on videotapes.
- A.C.T. (described in Segal, 1994) provides touch-coding (i.e. one key stroke input) and can be used both in reviewing video tapes and in real-time observation. However it does not provide VCR control. A.C.T. only runs on a Macintosh platform
- OCS Tools (Observational Coding Systems of Tools by Triangle Research Collaborative Inc., NC) is a set of tools that enable VCR control, time code reading, and input of annotation and coding. It runs on a MSDOS platform. The majority of the cases transcribed and coded in the current project were by OCS.
- VANNA (described in Harrison, 1991) is a Macintosh platform utility that allows the analysis of current multiple video sources (e.g. situations in which multiple cameras are used in recording). VANNA can display these video sources along with other time-stamped information on a single computer monitor, thus simplifying video review process.

2.11 A Framework for Studying Decisionmaking under Stress

In the current project, we adopted the framework (Figure 2.6) for studying decisionmaking under stress in a real environment.

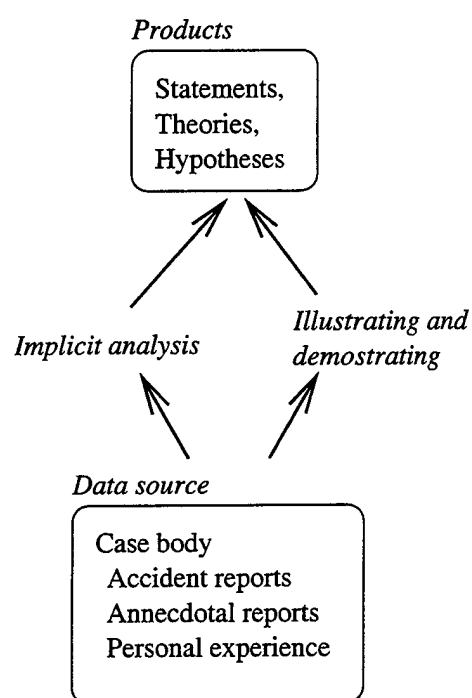


Figure 2.1: Implicit cognitive analysis: Statements were made based on an implicit process of analysis. Case data are used occasionally for demonstrating the proposed models, but rarely for supporting or verifying purposes.

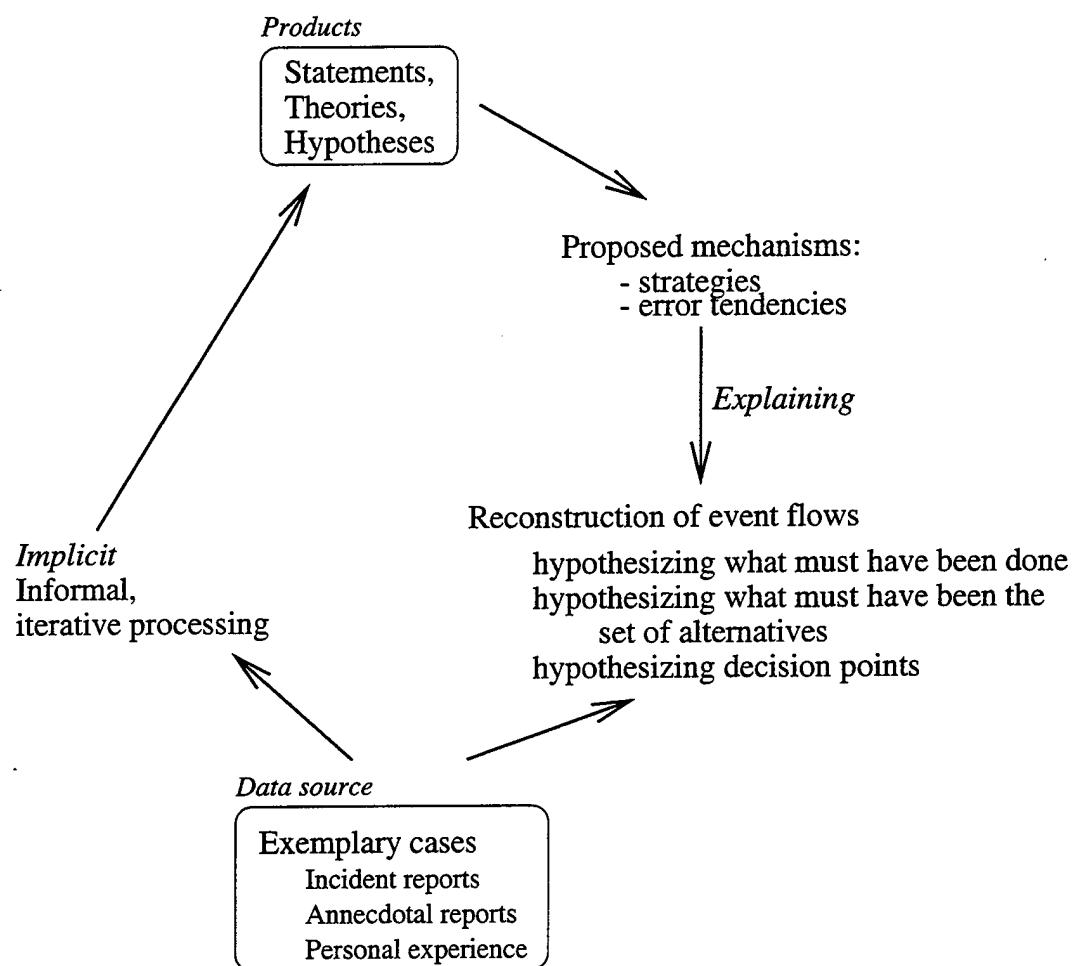


Figure 2.2: Exemplary analysis method: target cases were selected; the analysis and modeling are implicit. Case data are used for demonstrating the proposed models.

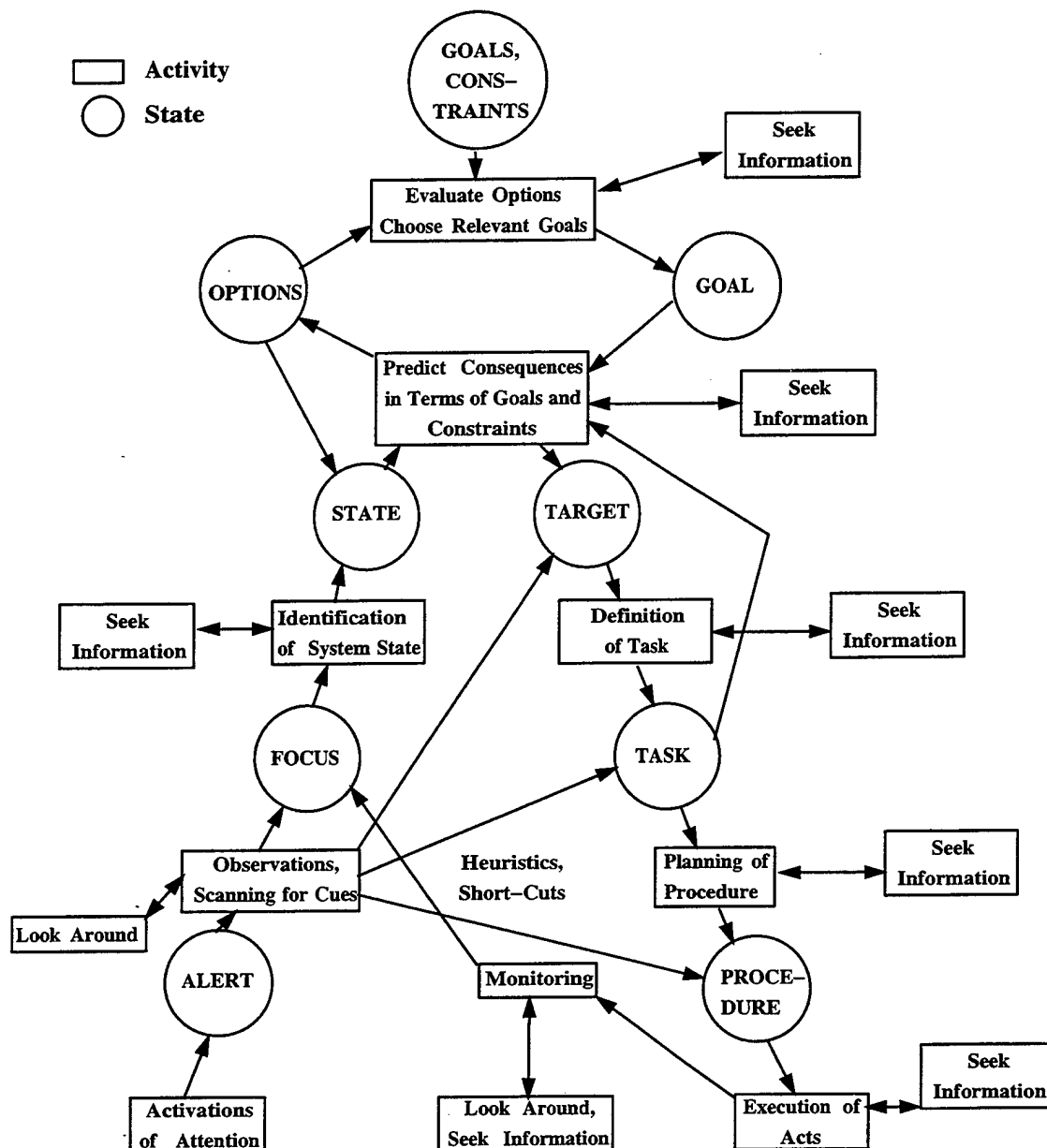


Figure 2.4: Rasmussen's decision ladder, adapted from Rasmussen, 1993, Fig.8.1. The ladder is a network with two types of nodes: information processing activities (in squares) and states of knowledge (in circles). The normative sequence forms the legs of the ladder; all other links (rungs) are possible routes of information processing activities in actual work settings. Note that several variations in the form of the decision ladder have been proposed by Rasmussen.

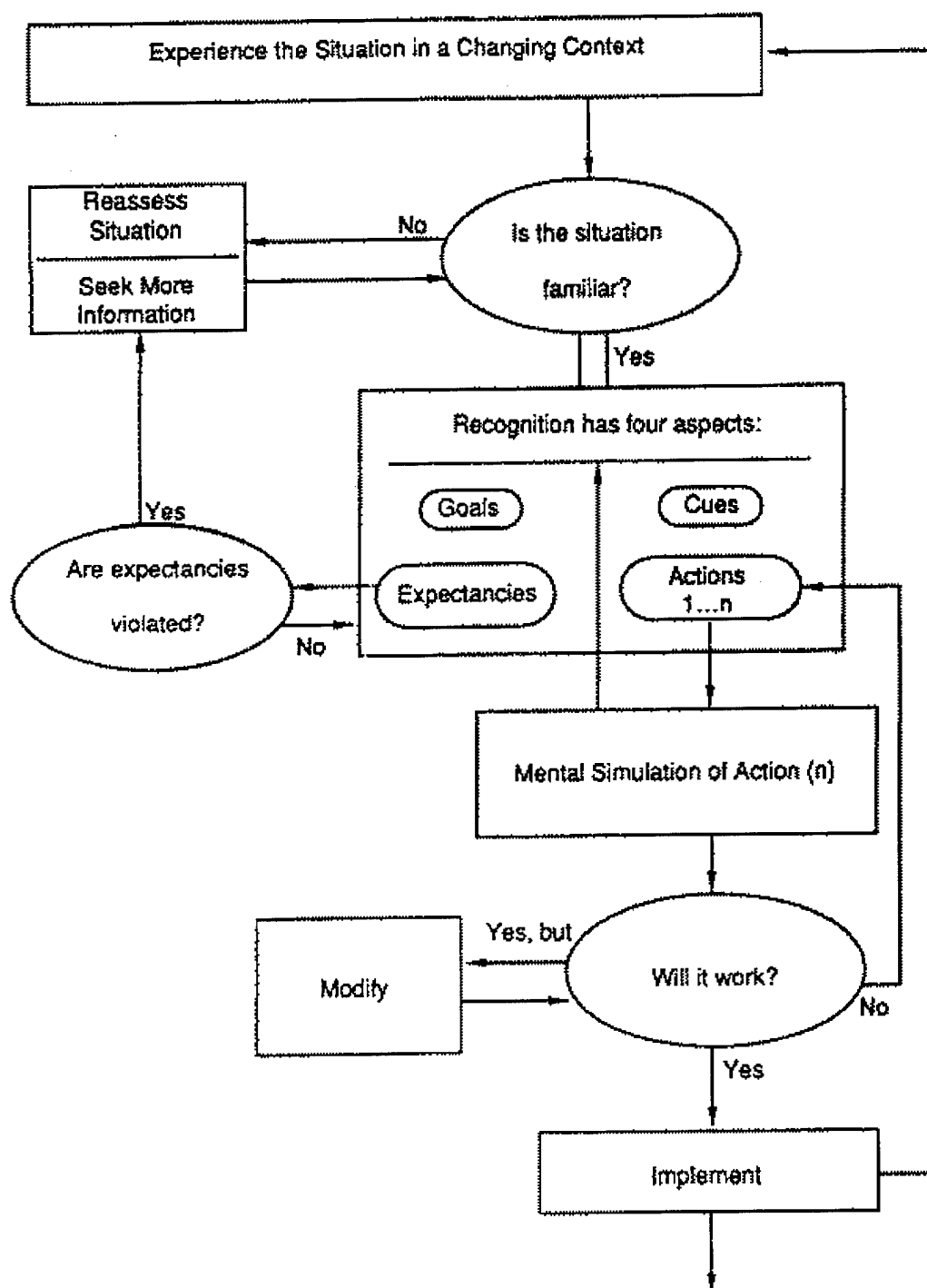


Figure 2.5: The recognition-primed decision model by Klein (1989)

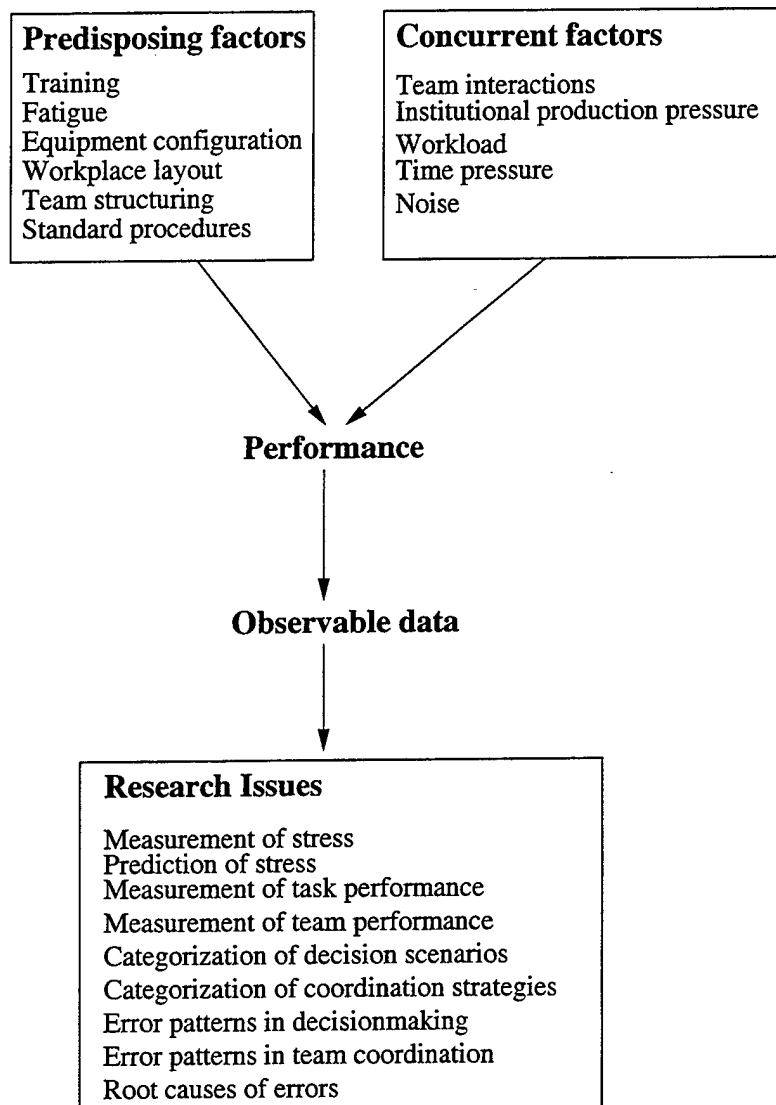
Performance shaping factors

Figure 2.6: A framework for studying decisionmaking under stress.

Chapter 3

Description of Trauma Patient Resuscitation

3.1 Trauma Patient Resuscitation

Trauma patient resuscitation is a specialized domain in which critically ill or injured patients are resuscitated and treated in a dedicated facility. (At the end of this report there is a glossary explaining the medical terms used in this report.)

Prototypical activities of a resuscitation session start with a radio dispatch from the field. Initial examination and resuscitation is done in a patient admitting area, 10 of which make up the trauma resuscitation unit. If needed, the patient is then transported to an operating room for further procedures. The first goal of the resuscitation team is to maintain the life process in the patient. A work domain analysis (Rasmussen *et al.*, 1994, Ch. 2) of the initial stages of trauma patient resuscitation produced a hierarchical representation of means-end relationship, which is shown as an abstraction hierarchy in Figure 3.1. The figure also describes the distribution of the responsibility among the team members.

The personnel in a typical team can be divided into three crews: surgical, anesthesia, and nursing, each with its own crew leader. The surgical crew has one or two surgeons, one of which is the assigned team leader, and an emergency medicine fellow. The anesthesia crew has a nurse anesthetist and one or two anesthesiologists. The nursing crew has one or two nurses and a trauma technician.

In comparison to other work domains, such as command and control centers, the teams in the domain of trauma patient resuscitation has the following characteristics: (1) Team members are closely located and share the same physical work space. (2) Team members are trained very differently (*e.g.*, surgical versus anesthesia). (3) Teams may contain personnel under training and their supervisors, even in regular operations. (4) The composition of each team changes from case to case, and work schedules of each of the three crews may rotate differently. (5) Resuscitation teams have not gone through extensive training in team work, and the roles and job specifications for each team member are largely the result of tradition.

During the analysis of team activities, we found that it was important to define who the team leader is in the domain of patient resuscitation. Although every resuscitation team

has an assigned team leader (the surgeon), he or she may not lead all resuscitation efforts. In particular, the anesthesia crew takes the full responsibility of airway management. During different stages of resuscitation different crews' activities may dominate the team and the leader in the dominant crew leads the team's activities. Thus the designation of team leader should be viewed as dynamic and task specific. In this report, all the references to team leader are made in this sense.

Resuscitation teams were situated in the patient admitting areas (see Figure 3.2 for an overview of the areas) and were surrounded by resuscitation equipment (e.g., intravenous fluids and airway management and monitoring equipment).

3.2 Characterization of the Domain

Uncertainty and time-pressure are two of the major characteristics of the domain of trauma patient resuscitation. Patients presenting for emergency care often have unknown medical histories that may include pre-existing diseases and allergies. The extent and mechanism of injuries may not be clear. While undergoing resuscitation, the patient's condition can change rapidly and dramatically, the pace of resuscitation activities is dictated by patient responses. There is a very brief window of opportunity during which a great deal can be done to save the patient's life. (For example, damage to the cerebral cortex can occur within a few minutes if the oxygen supply is inadequate.) Previous statistics have shown that about 80% of trauma deaths occur in the first four hours after injury (Brown, 1987). The time-pressure factor also compounds with the uncertainty, since the resuscitation team may not have the luxury of waiting for extensive patient monitoring information but have to act with what is available.

3.3 Tasks of Airway Management

Our investigation focused on an important part of trauma patient resuscitation: the management of the patient's airway (for breathing). Airway obstruction is a most rapid cause of death and protection of airway is the first priority in management of trauma patients. Adequate ventilation of the clear airway is the second priority and perfusion of the vital organs the third priority. Emergency airway management (known as intubation) is challenging in the trauma patient due to time pressure and uncertainty about the patient's injuries and because of labile vital signs. Intubation needs to be carried out expeditiously, because during attempts at the procedure, the patient receives no oxygen and is not ventilated. The trauma anesthesiologist is the team member who is responsible for management of the airway, providing ventilation and maintenance of physiological values of heart rate, blood pressures and oxygenation. In addition, the anesthesiologist may induce anesthesia often before the patient is stabilized or during the resuscitative effort, to allow surgical correction of trauma induced injuries. The acute management of major trauma, therefore, provides a rare opportunity to study both individual and team performance under stress in a setting that shares some of the same cognitive milieu as military decision making.

Tracheal intubation is a sequence of steps to pass a tube (endotracheal tube or ET tube)

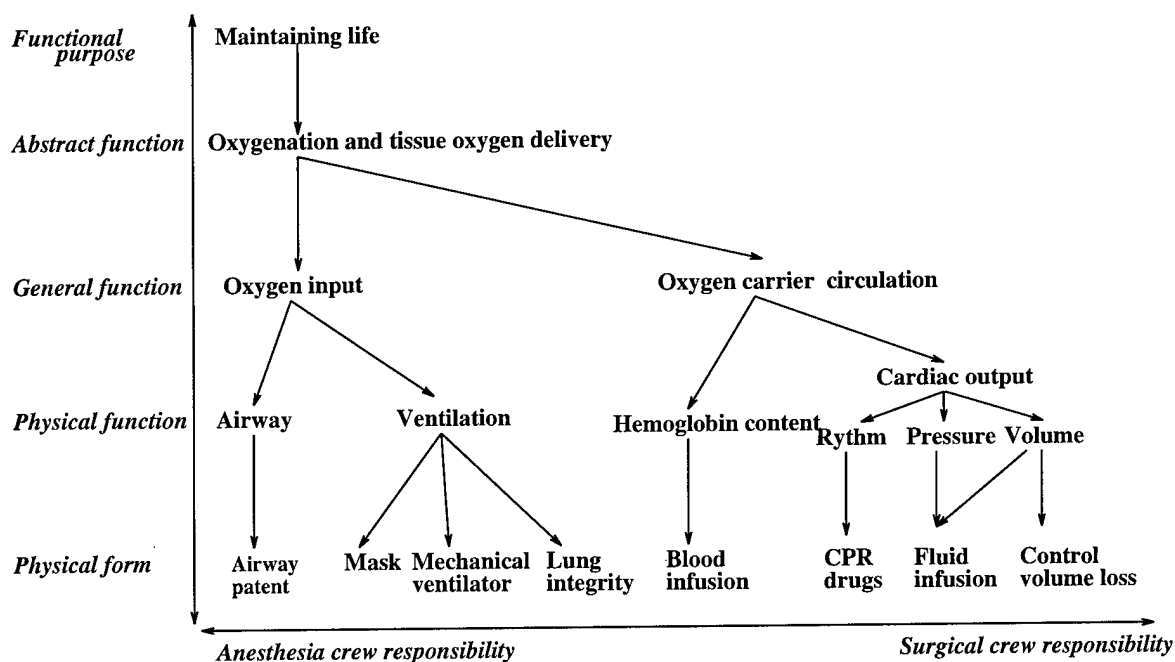


Figure 3.1: A means-end representation of the domain of trauma patient resuscitation. Only the key elements in each level are included here. Anesthesia crew's responsibilities are towards left side, surgical crew towards right, and shared responsibilities in the middle, although no sharp and stable distinction between the two crews' responsibilities exists.

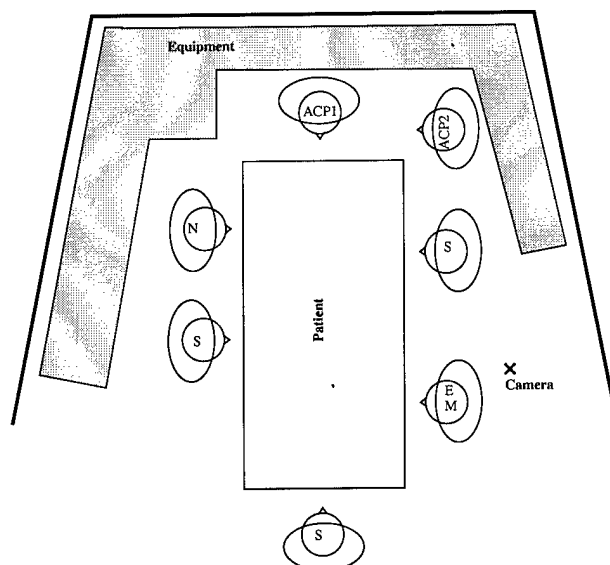


Figure 3.2: Admitting area layout. ACP: anesthesia care provider, S: surgeon, N: nurse, EM: emergency medicine physician. Note that the locations of the team members and the composition of the team were not fixed.

through the patient's mouth and vocal cords and into the trachea. Figure 3.3 is a photographic illustration of tracheal intubation. This procedure was chosen as the focus of our efforts for several reasons. First, the activities involved in intubation are reasonably well-defined, and intubation has a clear start and finishing point. Second, comparisons could be made across different types of cases as it is used in circumstances with variable time pressure. Third, it occurs frequently enough to allow a reasonable number of the procedures to be recorded. Fourth, the process of intubation is generally considered stressful and high in workload by clinicians.

Intubation is used when there is a need to protect the patient's airway (for breathing) against obstruction. For many trauma patients, spontaneous breathing and self-protection of the airway are compromised by injury (for example, if patients are in a coma or breathing is obstructed by blood). The first priority for emergency medical personnel is to ensure that the patient's airway is unobstructed and the patient is ventilated properly. In patients with a compromised airway or obstructed breathing, assurance of oxygenation and ventilation is achieved by intubation. The urgency for tracheal intubation in emergency care varies primarily due to the level of the patient's spontaneous breathing efforts and the nature of the injury suffered by the patient. If the patient is breathing adequately and there are no other indications to protect the airway, intubation may be delayed until the patient requires surgery.

The personnel involved in emergency care usually includes anesthesia care providers, surgeons, emergency medicine physicians, nurses, trauma technicians, and other specialists. It is the responsibility of the anesthesia care providers to perform intubation. While intubation is in progress, other care givers may perform other tasks, such as the placement of intravenous lines. In this report the term "team" is used to denote the emergency care personnel directly involved in the care of the patient and present in the vicinity of the patient, although considerable independence exists for the sub-groups of surgical, anesthesia, and nursing crews who compose the trauma team.

Six steps are involved in intubation. The first step (*pre-oxygenation*) is to build up oxygen reserve in the lungs by providing the patient with 100% oxygen. The second step (*induction*) is to induce anesthesia and muscle paralysis by intravenous injection of drugs to suppress the patient's gag reflexes to facilitate insertion of a tube into the trachea through the vocal cords. The third step (*laryngoscopy*) is visualization of the vocal cords through a special instrument (laryngoscope) inserted into the mouth so that the fourth step (*tube insertion*) of passing the Tube through the vocal cords into the trachea can readily occur. Direct visualization may be difficult due to blood and secretion in the mouth and the throat, which may require suctioning. In case of inadequate direct visualization, there will be initial uncertainty as to where the Tube is placed. The fifth step (*verification*) is to verify the position of the tube in the trachea by listening to the patient's chest (with a stethoscope) and by looking at patient monitors. It is essential to have the Tube in the trachea as opposed to the esophagus or the bronchus. If the Tube is mistakenly placed in the esophagus, which is next to the trachea, oxygen will be delivered to the stomach instead of the lungs and no ventilation and oxygenation is possible. If the tracheal tube is inserted too deep, it will pass into the bronchus and only one of the two lungs will be ventilated. The sixth step (*connection*) is to connect the Tube to a mechanical ventilator (an automatic device that delivers oxygen and other gases, and removes exhaled carbon dioxide) and confirm that the ventilator is functioning by repeated examination of the chest

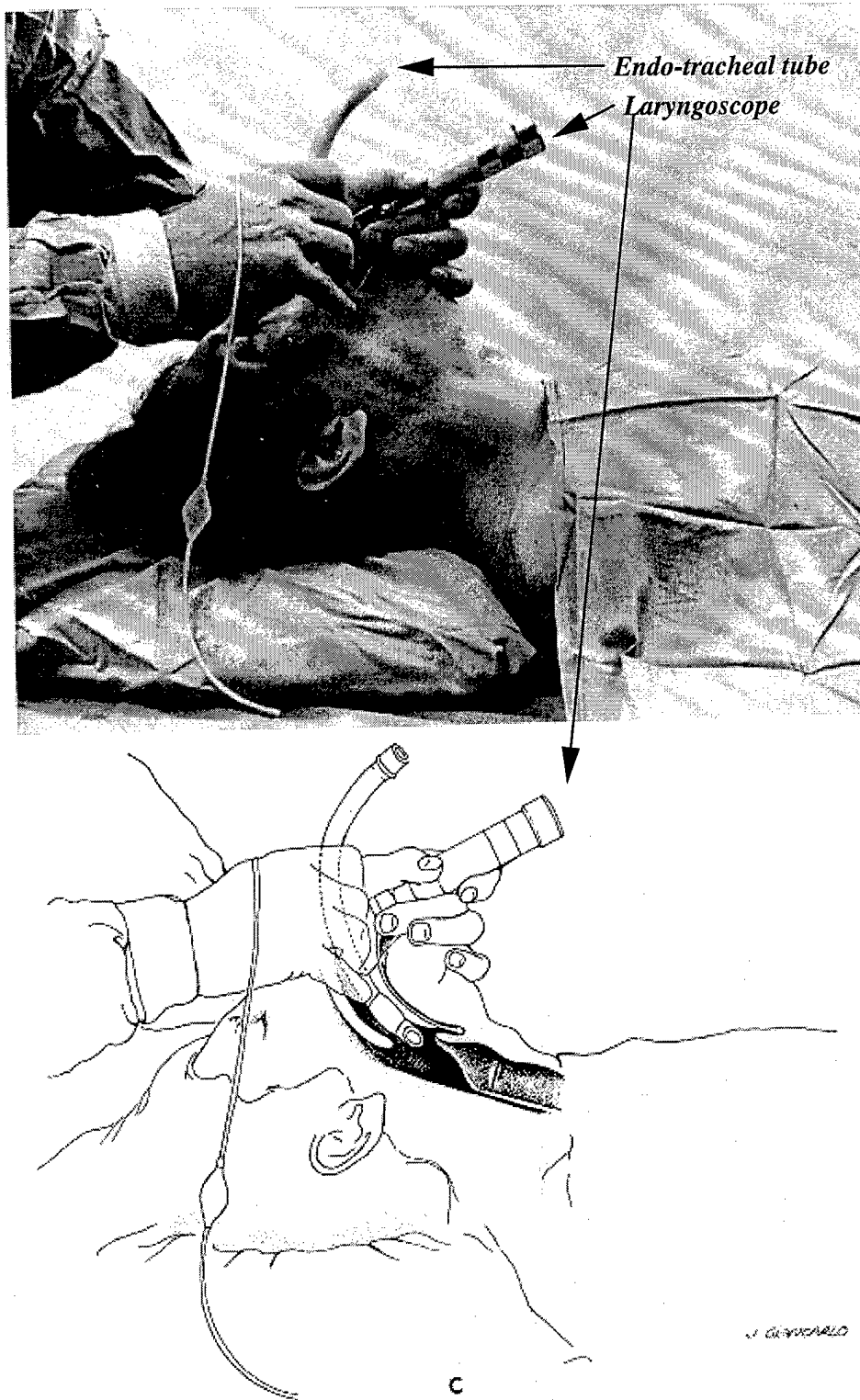


Figure 3.3: Tracheal intubation illustrated by photo and drawing, from Applebaum & Bruce, 1976.

or analysis of external gas for CO₂. Using a mechanical ventilator frees the clinicians' attention and hands so they can perform tasks other than patient ventilation.

3.4 Participants

The present data were collected in the R Adams Cowley Shock Trauma Center of the University of Maryland. This facility is a Level One trauma center that is regarded as one of the pre-eminent facilities of its kind in the world. As such, it serves as a training ground for trauma anesthesiology residents and faculty from all over the world. By drawing upon staff members involved in trauma anesthesiology over the course of an approximately four-year period, we were able to gather data from individuals spanning a wide range of age, trauma treatment experience, and training backgrounds.

Chapter 4

Acquisition of Audio-Video-Data

4.1 Audio-Video Acquisition System

To facilitate studying the activities of the team of anesthesia care providers, we developed an audio-video acquisition system. The audio-video acquisition system was designed to be turn-key operated and unobtrusive in order for video recordings to be easy to acquire. The result was that the clinicians would not be constantly aware of recordings and the equipment would not interfere with patient-care. Safeguards were developed to maintain confidentiality yet give the option of public display of the videotapes, or development of teaching vignettes.

Our attempt was different from all the previous efforts using videotaping of trauma resuscitation. A critically important difference in our video-acquisition system in comparison to all the other systems previously reported is that the audio-video recording system was interfaced with sensors attached to the patient. These sensors included monitors of heart rate, blood pressure, ventilation, oxygenation, temperature, and function of the heart (cardiac filling pressures). The digital output from these sensors was displayed as an overlay (updated every 5 seconds) on video images of videotaped events (Figure 4.1). Because of these interfaces with patient sensors, we were able to evaluate performance in normalizing abnormal values of patient vital signs (heart rate, blood pressure, oxygenation, and ventilation). Note that the decision-making in resuscitation of the trauma patient is directed at normalization of abnormal physiology. We compared performance on the videotape with that anticipated from normative decision trees we constructed for out-of-normal range (above or below) vital signs data. Analyses of decision-making (Figure 6.1) was assisted by plots of trends in vital signs data.

4.2 Overview of Video Acquisition System Network (VASNET)

Video acquisition by VASNET is fully automated. Insertion of a blank video tape into the video cassette recorder (VCR) boots a 386 Personal Computer (PC) via serial connections with the VCR, and activates the system (Figure 4.2). Ceiling-mounted miniature video cameras, vital signs monitors, and VCRs were installed in 4 locations (two patient admitting areas and two operating rooms) of the University of Maryland Shock



Figure 4.1: Video image of trauma patient resuscitation. This patient had a flail chest and major intra-abdominal bleeding. Vital signs show heart rate (HR) 91/min on extreme left. End-tidal CO_2 = 19 mmHg, O_2 saturation = 86%, and non-invasive BP = 62/39 shown on the right side of overlay. Time code is shown beneath BP.

Trauma Center. Vital signs data (blood pressure, heart rate, oxygenation, ventilation, and temperature signals) are overlaid onto the video image every 5 seconds. Recorded data is passed via a local area network, allowing remote monitoring of the data acquisition process (Figure 4.3). This Video Acquisition System Network (VASNET) has been in operation for 7 years, and is described in detail in Mackenzie *et al.*, 1995.

Videotaping of the process of resuscitating a trauma patient using VASNET provides an extremely detailed record of the activities of the team, and the physiological responses of the patient to interventions. Vignettes of such recordings are powerful teaching tools and we have used them to recreate the real environment in full version anesthesia simulators. The sound track, the timing of events, and other aspects of the videotapes acquired using VASNET may be useful in the development of multimedia simulations of trauma patient resuscitation. Potential other applications of VASNET include centralized remote monitors of patients in operating rooms, intensive care units, during transportation, in hazardous environments, and in the field. Such VASNET telemetry may facilitate the availability of expert opinions during medical and other consultations. The VASNET image and vital signs data can easily nowadays be displayed remotely via network, direct connection, digital cell-phone, or satellite link.

4.3 Strengths and Limitations of VASNET

The strengths of VASNET are that it has features not previously described in video acquisition systems including: overlay of video image and patient vital signs data on a single screen; automated saving of patient physiological data in digital format; simple turn-key operation; unobtrusive, robust design; accurate time recording; automated download/reset and message log; and the capability of remote system failure diagnosis, automated acquisition modification and monitoring.

The weaknesses of VASNET and other video acquisition systems used in real-life settings include: considerable maintenance was required to ensure that the system was always ready for immediate use. We maintained a log and during the worst months of 2 years use, the system was inactive eight times because of unplugging, turned off power, toggle switches were moved or other controls were altered. In a very few instances it did appear that these interferences were intentional. The longest maintenance free period in the 2 years was 13 days.

The patient sensor interfaces with vital signs monitors were disconnected for servicing of biomedical equipment and sometimes the interface connections, were not made with the replacement monitors. We instituted daily checks with a test videotape and maintained a written log at each location where videotaping occurred, to ensure that problems were identified and corrected. We developed a check protocol, that was soon learned and took about 5 minutes per location to complete.

In about 5% of the first 100 videotapes, communications among participants mentioned videotaping. The actions that resulted included pointing to the camera and included verbalizations about being on camera. In support of our belief that VASNET did not influence patient care, we did notice that participants acted naturally when managing the patients. In addition, the participants confirmed in their review of the videotapes that once involved in patient care they were so immersed that they forgot their actions were being

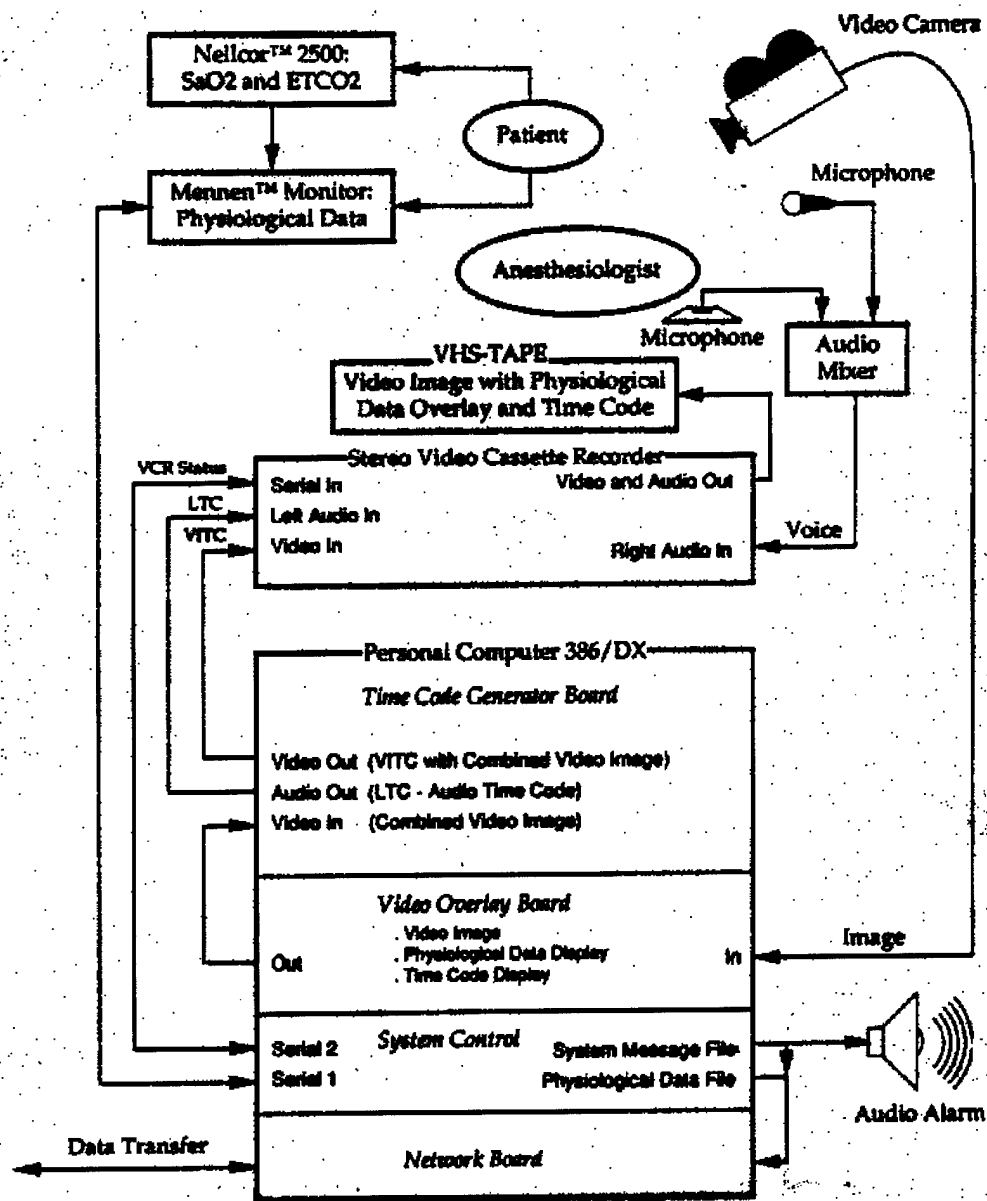


Figure 4.2: Video Acquisition System Network (VASNET). The video camera and two uni-directional microphones were permanently suspended from the roof of the admitting area of a trauma center. They were interfaced with a personnel computer located remotely behind the mechanical ventilator and a VCR fixed on top of the anesthesia cart. LTC: longitudinal time code; VHS: video home system; VITC: vertical interval time code; VCR: video cassette recorder.

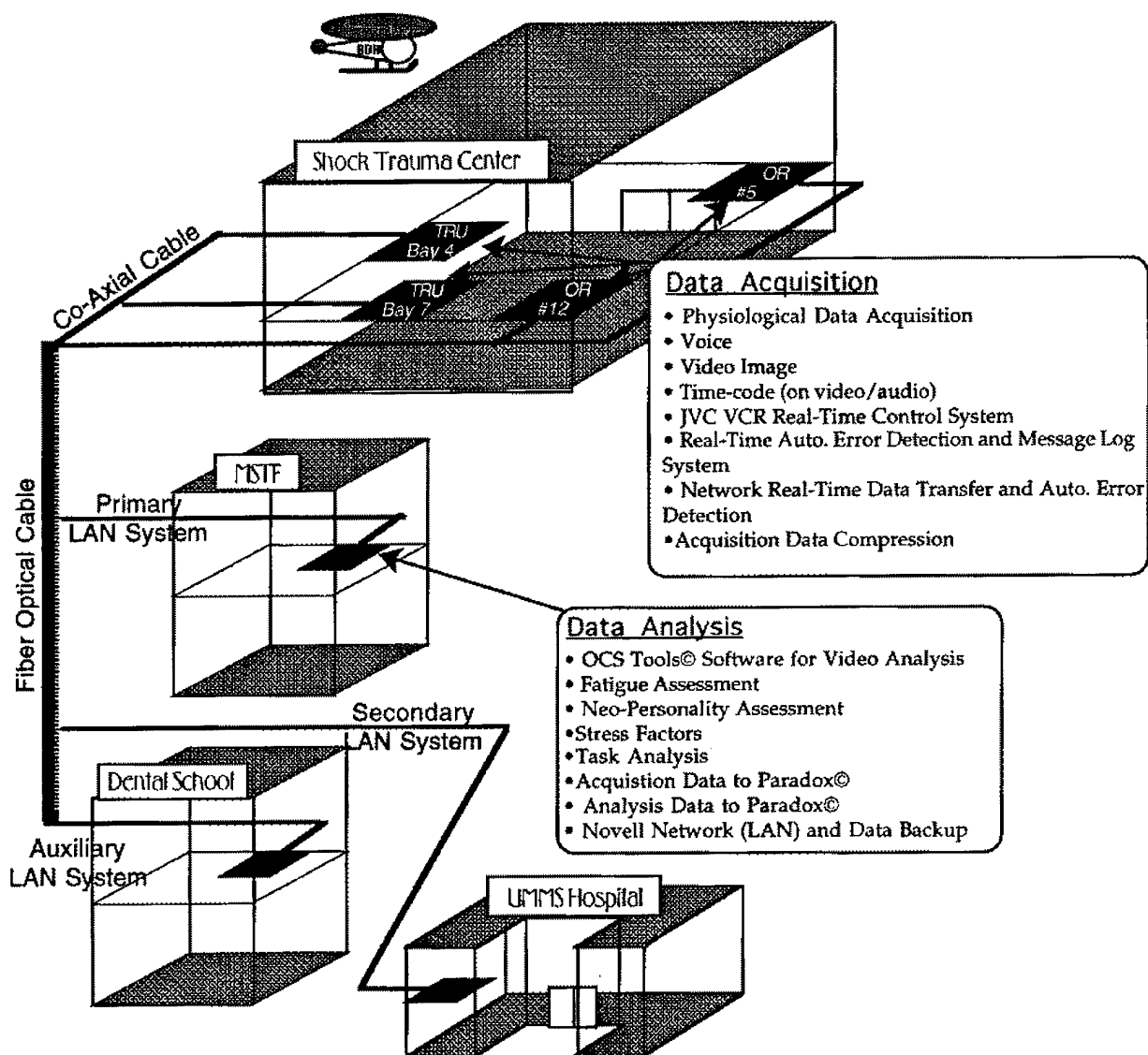


Figure 4.3: Network connections between two resuscitation areas (Admitting #4 and #7) and two operating rooms (#5 and #12) in the Shock Trauma Center. Back-up local area networks (LAN) are available in the Hospital and Dental School. The bubbles show essential elements of Data Acquisition and Data Analysis.

recorded.

The audio acquisition is variable in quality and the field of view may be obstructed by those attending to patient care especially during resuscitation. One solution to improve sound quality is to have the trauma care provider(s) wear microphones with wireless transmitters. We have not found obstruction of the field of view to be as much a problem in the operating room as it is larger and less overpopulated than is the patient resuscitation area.

Chapter 5

Data Collection in the Real Environment

5.1 Consent and Confidentiality

It required a considerable effort to gain approval to institute the current study and to obtain the renewal after 3 years of data collection. Initially all trauma care providers were notified, and arrangements made by the principal investigator (PI: Colin Mackenzie) to discuss concerns and answer questions. Approximately 15 meetings were scheduled over a 6 week period in which the outline of videotaping the anesthesia care providers was presented to nurses, surgeons, trauma technicians, operating room technicians, and other personnel who work in the resuscitation and operating room areas of the Shock Trauma Center. The protocol was submitted to the Shock Trauma Research Committee, to the Trauma Resuscitation Committee, and to the Operating Room Committee. The consent form and Institutional Review Board submission included the following provisions: 1) people who did not want to participate and unintentionally were videotaped in the course of patient care would have the option to have their image covered by a video-overlay mask; 2) the patients were *not* the subjects of the study, the anesthesia care providers were, so we requested that videotaping should occur without patient consent; 3) we angled the camera, and restricted the field of view so that it was extremely difficult to recognize the patient's face. If this was recognizable and for public display of video vignettes (at scientific meetings, etc.), a video-overlay mask would be used to maintain patient confidentiality. 4) The videotapes would be maintained under lock and key in the PI's laboratory, remote from patient care areas; 5) Quality Assurance Guidelines would be followed to maintain the maximum possible protection available under the law for these videotapes to be considered non-discoverable.

The IRB sent the protocol to the University and Hospital Legal Counsels for their opinions. The legal opinion was that although it was probably impossible to maintain these tapes as non-discoverable, they believed that they would create a favorable impression on any jury. The efforts of the 6-10 person trauma team around the injured patient gives a strong signal that everything possible is being done to resuscitate a particular patient. Risk management was also involved in the review of the protocol. Some 3 months after submission approval was given to proceed.

Despite the approval and discussions, there were still about a third of anesthesiology attendings and the majority of nurse anesthetists who refused to participate. However, once underway, we were able to gather ample data with a core of 10 or so participants.

The renewal request for continued IRB approval was submitted 2 months before the renewal date to ensure continuation of this funded project. The protocol was again submitted to legal counsel. The consideration of the protocol was delayed for 2 months until the protocol expired. The protocol was not renewed until 6 months later. All videotaping had to cease and after numerous meetings, letters to the Dean (of the School of Medicine of the University where the study was conducted), etc., we obtained agreement to proceed. The major hold-up was that the IRB believed that we were coercing the anesthesia care providers to participate. We were able to show that, in essence, the participants (described in all of the papers published as the Level One Trauma Anesthesia Simulation Group - or LOTAS group) were all co-investigators whose names appeared on the papers. In other words, implied approval was given by the participants.

5.2 Recording of Activities during Resuscitation

For each admitting area, a fixed miniature video camera was suspended from the ceiling, with microphones mounted immediately above the patient's head and feet. The video images were overlaid with patient physiological data, which were directly obtained from patient monitoring equipment. (Equipment list and configurations are described in detail in Mackenzie *et al.*, 1994.) The attending anesthesiologist and/or the nurse anesthetist started the recording voluntarily, just prior to the arrival of the patient. Along with video tapes, the participants in a case were requested to submit patient records for later review and to complete a questionnaire about the case (see the post trauma questionnaire attached). The patient records contained basic information about the patient status prior to admission and treatment received (such as drug names and doses). The questionnaire was used to obtain the anesthesia care providers' own performance assessment as well as any unusual circumstances (*e.g.*, fatigue). All patient identifiers were removed to preserve confidentiality.

5.3 Companion Data Collection

The participants and non-participant subject matter experts (SMEs) were requested to review video tapes and to provide commentaries, usually within a week. Interviews were conducted for a small number of cases where what had occurred appeared to be unclear. Over 100 cases were so video taped over the three year period, and they covered a wide variety of cases and team compositions. No efforts were made to screen out any particular types of cases, and in fact it was difficult if not impossible to predict the cases to be recorded.

Data collection was organized by treatment sessions (*i.e.* cases). A treatment session, of course, pertains to a particular patient, but there may be more than one session analyzed for a given patient, for example, when separate recordings are made in the admitting area

and in the operating room for a given patient. For each session, the overall strategy is to extract information from the following sources:

- Videotapes from the treatment session with that patient
- physiological data that was logged from that patient during the treatment session
- The hard-copy anesthesia record or admitting area consultation form that was completed by the anesthesiologist for that session
- The post-trauma questionnaires that were completed by the anesthesiologists and/or CRNA for that session
- An anesthesiologist subject matter expert, preferably one of those who participated in the video taping, viewed the tapes along with the data analyst
- Surgical summary or procedures carried out and Laboratory blood analyses, obtained through Shock Trauma Computer Network.

5.4 Fatigue Measurement

Synwork was used to assess the ability of anesthesiologists to carry out four simultaneous tasks over a five-minute period. The tasks tested are similar to those performed in clinical anesthesia and include monitoring of visual and auditory signals, setting alarms, mental arithmetic and short-term memory storage and retrieval. We used Synwork to determine whether there was a decrement in performance of these tasks over a twelve-hour period and compared night with day shifts.

Each anesthesiologist achieved asymptotic performance on Synwork during ten practice sessions (Fig. 5.1). Synwork was then performed at the start, middle (7-8 hours after start) and end of a 12 hour shift, both during the day (7am-7pm) and at night (7pm-7am). Testing was performed randomly over a three-week on-call period for up to three day and night shifts per subject with a minimum of twelve hours rest between each shift. Results were compared by paired t-tests ($p < 0.05$ was significant).

Results There were no differences between total scores on Synwork at the start, middle or end of a 12 hour day or night shift (Fig. 5.2). Nor were there differences between daytime and nighttime scores. In addition, we examined the four individual components of Synwork (memory, math, visual, auditory) and found no differences between nighttime and daytime performance in the four components or in performance of these four tasks within the twelve-hour shift.

Synwork has previously been used to assess performance of combat pilots and the effects of sleep deprivation. The similarity of the multitasking software to the tasks of anesthesiologists make it a potentially useful assessment of fatigue in the clinical environment. During 12-hour shift work, we were unable to detect any decrement in performance of Synwork either in total score or in any of the individual components.

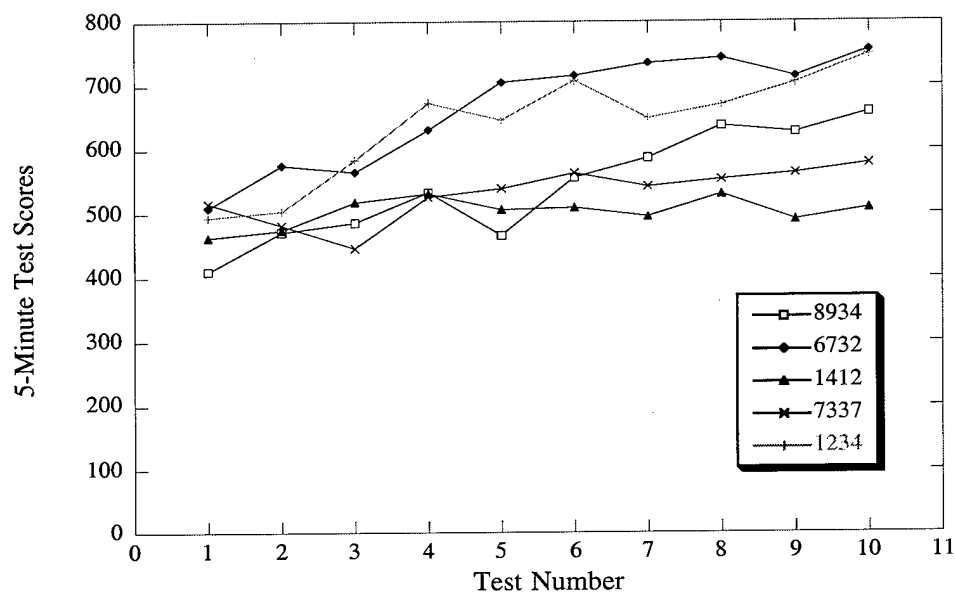


Figure 5.1: Practice Synwork scores of five subjects studied (labeled by four digit identification numbers) showing asymptotic performance after 6–8 attempts.

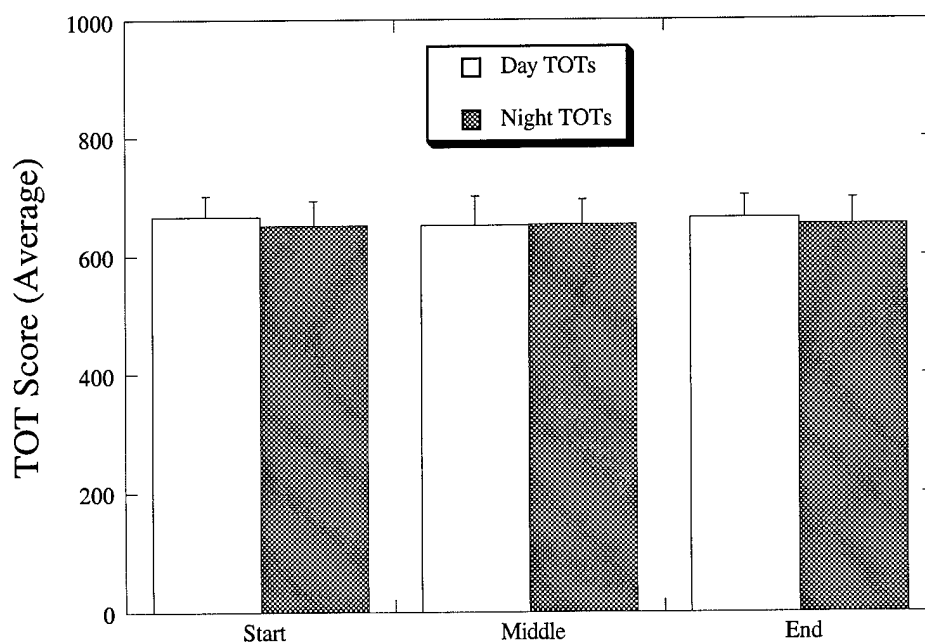


Figure 5.2: Mean and standard errors of total (TOT) Synwork scores for day and night at three point during a shift: start, middle, and end of a shift.

5.5 Post-Trauma Questionnaire

Immediately following a videotaped session of acute trauma patient resuscitation and treatment, a 30-item Post-Trauma Questionnaire (PTQ) was completed by the lead anesthesiologist, and occasionally by an assisting anesthesiologist or Certified Registered Nurse Anesthetist (CRNA). For our purposes, the lead anesthesiologist was considered to be the care provider who had overall professional responsibility for the patient and was responsible for hands-on care of the patient. Sometimes the care provider who completed the questionnaire was supervised by another person. In some cases both the lead anesthesiologist and the hands-on care provider completed questionnaire.

The PTQ was a pencil and paper questionnaire which solicited information on aspects of the case, the team, and the individual care provider. The PTQ was developed by trauma anesthesiologists in conjunction with experimental psychologists, and included requests for comments on identification of case difficulty (on a scale with extremes of best/worst, most/least), own performance, the occurrence of stressful events, misjudgments in management and whether the same management would be repeated. Additionally, the PTQ asked for subjective assessments of perceived stress, fatigue, case difficulty, ones own performance, team-work and effectiveness on interaction with specific team members (e.g., separate items for surgeons, CRNAs and nurses). We have 89 completed Post-Trauma Questionnaires.

Fatigue: There were five items on the PTQ that quantify fatigue:

- the number of hours last slept
- the number of hours awake (since last slept)
- what hour of the shift did the case occur
- how long ago was your last shift (in days)
- the number of hours during the present shift actively involved in patient care

Experience: There were four items on the PTQ that quantify experience. Additionally, there were two demographic items from a demographic form completed by participating anesthesiologists, that also quantified experience.

- the number of cases similar to the current case, (that the anesthesiologist has ever managed)
- how long it has been since the anesthesiologist has managed a similar case
- the number of times the anesthesiologist has worked with the 'duty' surgeon
- how long it has been since the anesthesiologist has worked with the 'on duty' surgeon

The demographic:

- years as an anesthesiologist
- years as a trauma anesthesiologist

Patient Injury Severity: There are four items on the PTQ that quantify patient injury severity. They are standardized trauma ratings, assessed at the time the patient arrives. The scales are:

- Abbreviated Injury Score (AIS)
- Glasgow Coma Scale (GCS)
- American Society of Anesthesiology, physical status (ASA)
- Trauma Anesthesiology Grade (TAG)

A linear scale was provided for each subjective assessment. SMEs were asked to rate their perceptions by marking the appropriate position on the linear scale. They were requested to assess how they perceived stress, fatigue, and case difficulty on a scale anchored at each extreme by 'most' and 'least'. Additionally, the participants were also asked to rate their perception of their own performance, team-work, and the effectiveness of interaction among team members on a scale anchored at each extreme by 'best' and 'worst'.

Chapter 6

Video Analysis

6.1 Introduction

The current project collected over 200 hours of videotapes of real life trauma patient resuscitation. These videotapes are accompanied by medical records (admission records, anesthesia records, discharge summary, laboratory tests, and physiological recording of the patient). This large amount of information posed an immediate analysis challenge. A number of questions needed to be addressed:

- How to measure performance?
- How to code verbal and nonverbal communications?
- How to measure stress?
- How to review the video tapes systematically?

We will first describe a video analysis tool developed as a result of the current project. We will then describe the performance measures developed and how it was used in the data analysis. We will describe the stress measurement technique used later.

6.2 The Environment for Video Analysis (VINA)

One feature of the data collected in the current project is that each case is accompanied by multiple documents indexed by time. As reviewed earlier, the tools available were inadequate in dealing with the data collected. Frequent references were made in the analysis of videotapes between videos, records, and transcription of verbal communications.

The Environment for Video Analysis (VINA) was developed for efficient handling of video data for the purpose of analysis, coding, critical review, and precise control of video presentation in experiments. The analysis of video-audio data often requires quick cross-checking and referencing among time line documents as well as between time line documents and video images displayed on the TV monitor, where time line documents can be in the form of transcripts, codings of events and activities, vital signs, etc.

VINA has the following features:

1. manual and scripted VCR control
2. VCR control by pointing, click-and-drag
3. automatic tracking (highlighting) of records in multiple time line documents by synchronizing with time code on videotapes
4. touch coding of events and activities
5. temporal graphic representation of codings
6. digital and graphical display of recorded vital signs data synchronized with VCR.

A sample screen dump is in Figure 6.1.

6.3 Overall Methodologies of Video Analysis

Given the huge amount of data and the many variables that were studied, the video analysis was to make full use of the information captured on video recordings and a variety of methods of data extraction were utilized. Most of the analyses were performed surrounding intubation: from the point of pre-oxygenation (using a tight fitting face mask) to 10 minutes after the tracheal tube was secured in place with tape. Figure 6.2 shows an overview of video analyses.

The video analysis process started with a review of the admitting area or operating room anesthesia records and the completed post-trauma questionnaire (PTQ; described earlier). The anesthesia records documented events as they were occurring and were the legal records of these events. The PTQ, which was designed for this project, was completed by the anesthesiologist and nurse anesthetist (if involved) after the treatment session was complete. In addition, the Surgical Summary of the patient admitting area and operating room events was accessed via the Shock Trauma Computer Network from our video analysis work station in the Anesthesiology Research Laboratories. The surgical summaries identified briefly the extent and site of injury and provide an overview of the type of trauma and the physiological state that the patient was in on admission. For surgery they identify the reason for surgery, the operative findings, the surgical procedure carried out and any complications that occurred. An abstract (up to 500 character summary) of each case was derived from these sources and entered into a Paradox database file.

6.3.1 Intubation Analysis

In order to systematically analyze performance, decisionmaking and stress, a questionnaire was developed. The questionnaire, called Intubation Analysis (IA) form, contained 75 items of multiple choices, open questions, and linear scales. IA forms were used to allow each SME reviewer to analyze each case in a similar manner. Appendix 1 contains a copy of the IA forms used. Within the IA form, the performance of the task of

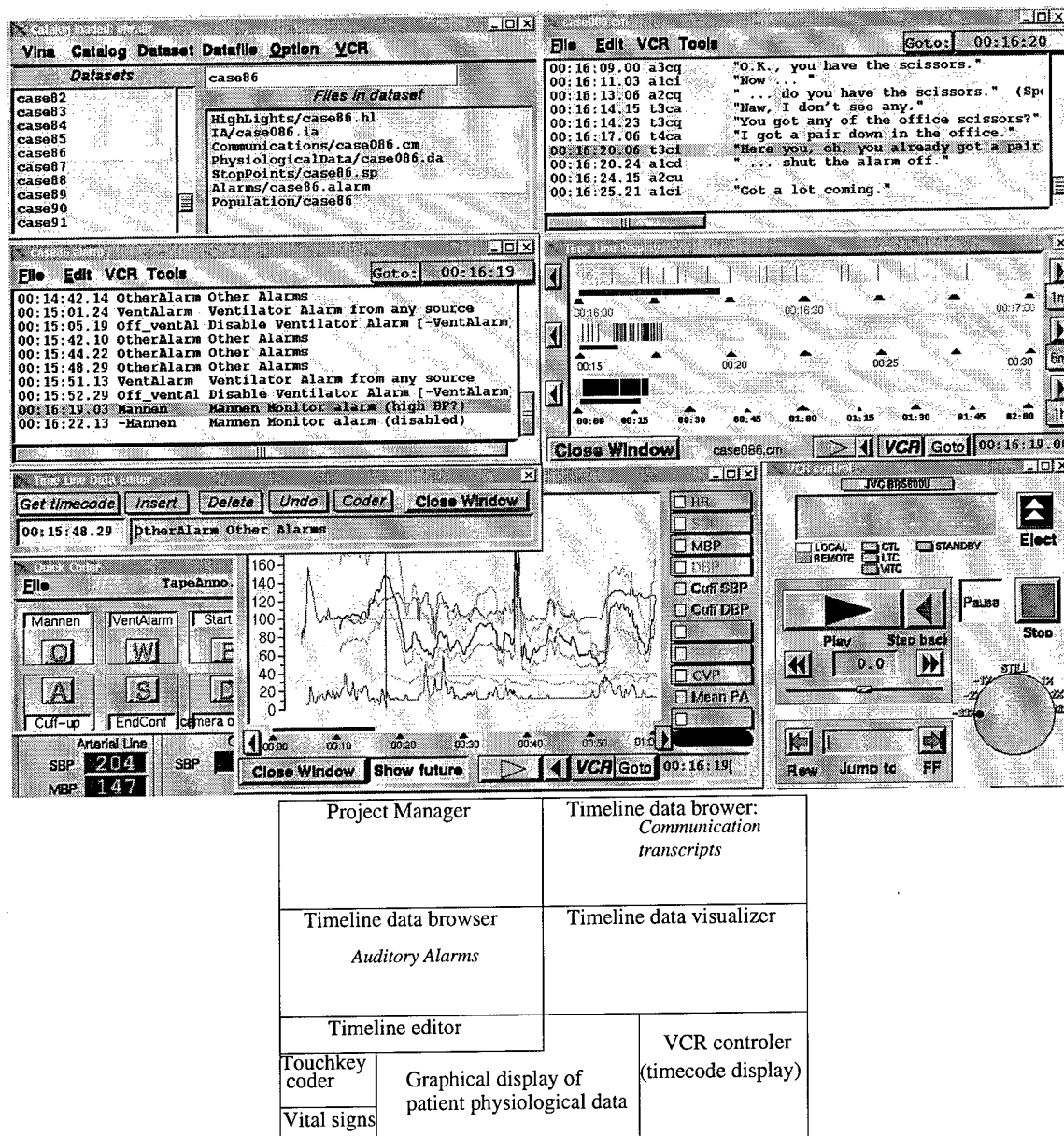


Figure 6.1: VINA: An environment for video analysis. Shown here is a screen dump (top) during the coding of auditory alarm events. The screen dump is explained in the bottom layout diagram. Current lines in landmark event window, the coding window, and the transcription window are automatically high-lighted to correspond the time code read directly from the VCR. The touch coder allows touch coding without stopping VCR. The graphical display of vital signs allows detection of abnormal trends and can position videotapes at interesting points with a click of a mouse button.

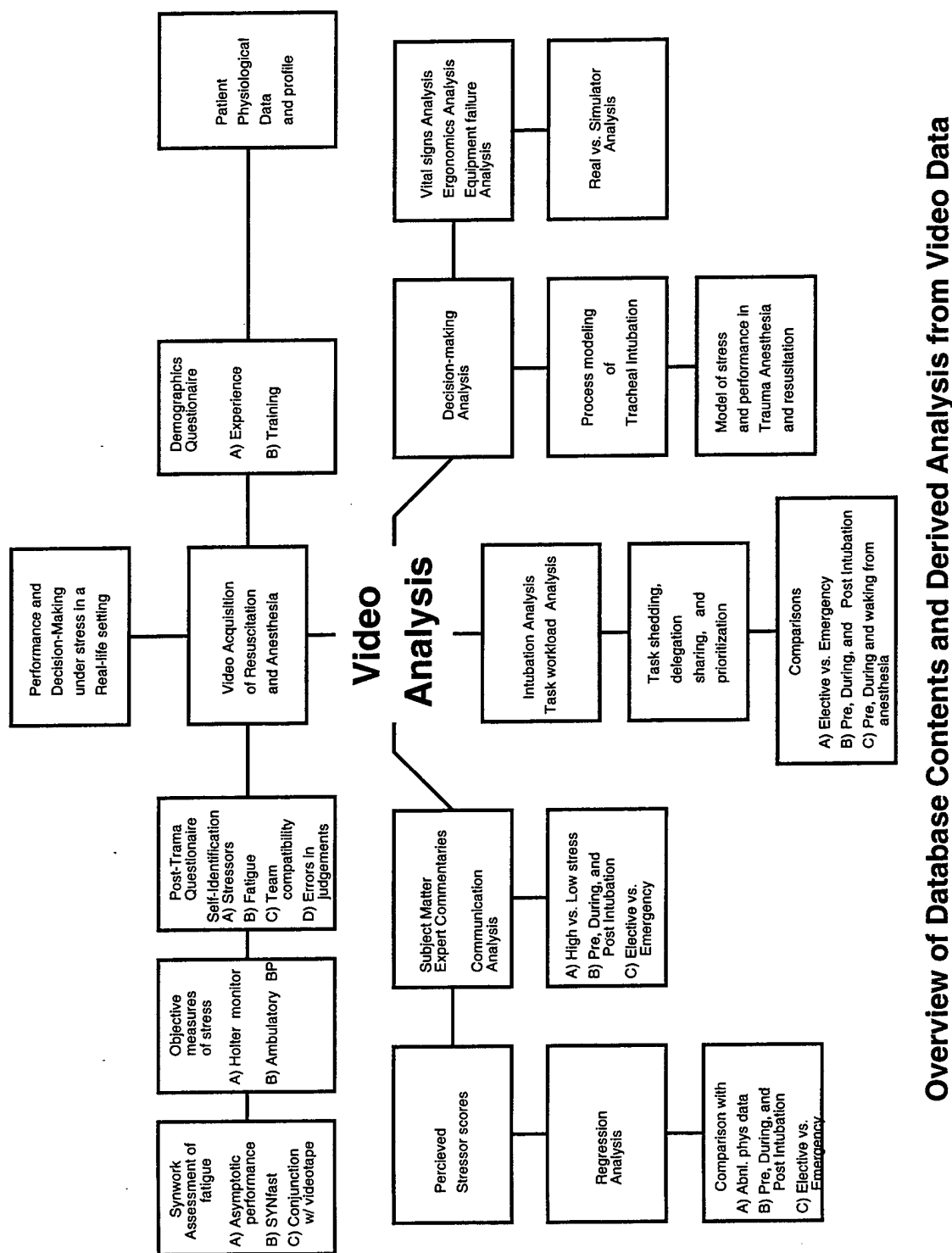


Figure 6.2: Overview of database contents and analyses from video data.

intubation was defined by a sequence of predetermined steps which were assumed to be normally or ideally carried out by anesthesia care providers. The task list is shown in Table 6.1.

Apart from the task sequences listed in the table, landmarks were identified and timings were noted. The results were entered into a Paradox database.

6.3.2 Commentaries

As soon as possible after a case was taped (usually within several days), a data analyst reviewed the tape along with the lead anesthesiologist whose performance was recorded. The commentaries from the participant SME and non-involved SME were coded in OCS Tools. On an ongoing basis, the SME was asked to elucidate the tasks that each team member was involved in and to verbalize, as much as possible in retrospect, what his/her thought processes were with regard to considering alternative treatment strategies. The tape was paused from time to time for the SME to relate the status of the case to any of the decision trees that were appropriate. When one or more decision trees could be seen as having been operative, the SME was asked to conceptualize the extent to which they considered each choice point, what factors mitigated this choice, and whether other factors not currently represented in the tree came into play. Based on this structured interview (which was itself audio recorded and transcribed) the data analyst then coded the team's task activities and behaviors. Each logged entry was related to the time stamp from the video and explanatory notes described any behaviors or verbalization that particularly reveal decision-related considerations or team coordination. In addition another knowledgeable anesthesiologist SME who was not involved in the case under examination, also reviewed the tape in the same manner and was consulted for clarification or further explanation about the clinical activities or discussion that was generated from observation of the tape.

6.3.3 Perceived Subjective Stress Ratings

A structured interview process was used including the subject matter expert (SME) being asked for subjective rating of six stressors (noise, team interaction, interaction within anesthesia care providers, time constraints, task workload, and diagnostic uncertainty) and one overall stress at one minute intervals during intubation. SMEs reviewed videotaped tracheal intubation procedures and rated on a 5-point rating scale the perceived stress imposed on the resuscitation team. The rating scale used measured 7 items: one overall stress and six potential stressors, which are described in Table 6.2. These stressors reflect environmental (noise), social (interaction with other team members), and task related (time constraints, task workload, and diagnostic uncertainty) factors. The six stressors were chosen after consultation with practitioners and were put forward as measures of potential contributors to the overall stress.

Prior to the start of collecting ratings, the raters were given instructions about the collection procedure and a description of the 7 measured items (the 6 stressors and overall stress ratings). The raters were also given the patient's case history that contained information about the medical status of the patient on admission. Raters reviewed videotapes individually.

PI	Pre-Oxygenation
PI	Head Positioning
PI	Need for cricoid pressure ascertained and felt for
PI	In-Line stabilization (neck not cleared)
PI	Suction ready
PI	S _a O ₂ monitor placed pre-induction
PI	ETCO ₂ monitored pre-induction
PI	BP monitored pre-induction
PI	HR monitored pre-induction
PI	IV running pre-induction
PI	All anticipated drugs drawn
PI	Drugs given appropriately
PI	Stethoscope at hand
PI	Cricoid pressure applied correctly
PI	Check for means of ventilating with 100% oxygen
PI	Assistance immediately available
DI	Intubation equipment ready
DI	Check of Neuromuscular block before laryngoscopy
DI	Re-oxygenation after three attempts
DI	Modification of technique between attempts
DI	Re-oxygenation after 2 minutes of attempts
DI	Re-oxygenation if S _a O ₂ falls below 95%
DI	Cricoid pressure maintained till position of ET tube determined
DI	ET tube cuff inflation to just seal
DI	Tube insertion distance checked
DI	Auscultation of both sides of chest
DI	Auscultation of both sides of chest by intubator
DI	Auscultation of upper abdomen
DI	Rechecking inflation if cuff is not inflated to just
AI	ET tube held till taped or tied
AI	Listening to the chest after connection of ventilator
AI	CO ₂ monitored within 2 minutes of intubation
AI	CO ₂ monitored within 4 minutes of intubation
AI	Check neuromuscular block before giving the non-depolarizer
AI	Check of ventilator parameters

Table 6.1: Task list for tracheal intubation. PI: pre-intubation; DI: during intubation; AI: after intubation.

Subjective ratings were collected at predetermined time points specific to each case. These time points covered up to 10 minutes of the preparation for intubation, the task sequence of tracheal intubation, and extended for 10 minutes after intubation succeeded. The time points were exactly one-minute apart. Because cases progressed differently, the number of data points was different for each case. The duration between the start point of intubation (identified as the event of mask ventilation with 100% oxygen) and the success point of intubation (identified as the seal of the cuff on the breathing tube) were also variable across cases.

The video playing equipment was controlled by an assistant, who played the video tape and stopped at each time point to gather subjective ratings on each of the 7 items. A fixed order (first the six stressors as they were described in Table 6.2 and then the overall stress) was followed in the gathering of the 7 ratings. The assistant recorded the ratings in a chart and later entered them into a database when the videotape review was finished. (See Appendix for the form used.)

6.3.4 Communication Analysis

Verbal communications audible on the video recordings were transcribed and time-stamped into OCS Tools. We quantified the frequency, content, and patterns of verbal communications among the trauma team during selected cases. Results indicated that there were systematic differences in verbal communications during periods entailing different levels of stress. Comparisons were made between cases involving high and low injury severity and between various segments of particular cases, ie pre-, post- and during the induction/intubation of the patient. Verbalizations were categorized into ten types – communicating with the patient, undirected comments to oneself, asking task relevant questions or for assistance, providing an answer to such a query, providing task relevant information unsolicited, communicating a strategy, giving directions, other task relevant comments, and non-task relevant comments. Counts of the number of each these types of verbalizations were tallied for two minute periods before, during, and for ten minutes after induction/intubation. Results from six cases suggested that during periods when the team functioned under higher stress, verbalizations tended to increase, often occurring simultaneously, and their content became more focused on task-relevant comments, particularly requests for assistance and information. Surprisingly, strategic decisions were not often communicated explicitly.

The transcriptions were coded using OCS Tools software. Separate data files were created from each pass and they were then merged into a single master data file for the videotaped session.

Event coding The first pass provided overview of the session by coding general comments about the patient's condition at various times, significant events that occurred, and subjective ratings of anesthesiologist workload. This pass was completed by a video analyst with support from one or more anesthesiologist subject matter experts (SMEs), if possible including one of the SME involved in the case (ie one of the care providers on the videotape). The intent was to get into the data file a skeleton account of what transpired during the session along with retrospective subject ratings of the degree of

stress present. In so doing, we solicited information and clarification from the SME that could be used by the data analyst in subsequent coding passes.

While the eventual interest was in characterizing anesthesiology-related activities, the focus of this first pass was more on the major events that occurred in the patient's treatment as a whole, rather than behaviors on the part of the treatment team. The events included changes in the patient's condition (eg cardiac arrest, physiological variable passing into normal or abnormal ranges), milestones in the course of the treatment (e.g. successful intubation), major interventions (eg administration of drugs, cricothyroidotomy), and other major occurrences that were readily apparent (eg equipment alarms, equipment failures). As indicated in the attached list of Observation and Coding Systems tools (OCS), tools codes, alarms, physiological abnormalities, and certain treatment interventions are coded accordingly. General comments and miscellaneous events were coded with generic miscellaneous codes in order to time stamp the entry with a brief note.

While viewing the tape the SME "talked through" the case, identifying events and behaviors of interest and speculating about the participants "thought processes" as appropriate, while the video analyst coded as much of the event information as possible in real-time. The SME's comments were audio recorded on a Dictaphone, so that they could be referenced in subsequent coding passes. With the help of video analysis tools, the video tape could be stopped, rewound, or advanced quickly as needed. In order to relate the audio dictation to the video tape, the video analyst intermittently verbalized the time code that was being displayed on the video tape.

Video analysis passes were referred to as an A pass if made by the participant SME who was videotaped. Among the 96 videotapes 82 A passes were completed. During the A pass the SME provided subjective stressor ratings, which will be described later. In addition to making the stressor ratings, participants also audio recorded running commentaries during their first viewing of the videotape. The audio recordings were transcribed and entered into the database using OCS Tools software with time-stamps to allow synchronization with patient physiological data and audio recordings and video images on the videotape (which were identically time-stamped).

The B pass was carried out by a non-participant SME in the same manner as the A pass. In B pass the audio commentary was given from the perspective of someone who had not been present during the original videotaping and who did not participate in patient management. The B pass SME was however, familiar with the environment and trauma patient resuscitation and anesthesia.

The C pass was carried out by our video analyzers who transcribed the communications from the sound track of the video recordings. These commentaries were coded using OCS. The transcriptions were reviewed by SME's and typographic and other translational errors were rectified. The commentary was entered verbatim and simultaneously coded by the video analyzer in OCS Tools software. These communications and codings were thus also time-stamped. Team performance was of interest here, so all recognizable verbalizations were coded. In addition, the presence of background chatter (unintelligible verbalizations) and periods of silence were coded. Again, the coding scheme included both codes from the action and for the agent.

The D pass was a re-review of the videotape by the participant SME in which cognitive processes and task analysis occurred. Some of this was done during the A pass and

some participant SME's were better than others in incorporation of "thinking aloud" into the A pass. The object of the D pass was to focus on decision making and task workload.

In addition to the information available in the A-D passes, we also implemented a further video pass that specifically examined patients who underwent emergency or elective tracheal intubation on the videotape. These reviews were carried out independently of the video analysis personnel. We have developed a questionnaire (Appendix 1) that analyzes performance of the emergency or elective tracheal intubation. Performance in this context, is assessed by the completion of 15 activities usually conducted in preparation for tracheal intubation before the event, 10 activities carried out during intubation and 6 activities carried out after intubation. In addition, this independent video-review determined (a) how well the anesthesia care providers used the available patient physiological monitors, (b) identified difficulties that occurred, (c) assessed psychomotor skills, and factors that impaired these skills and how much they delayed the accomplishment of tracheal intubation, (d) identified errors in decision-making and the occurrence of skill-based and knowledge-based errors and contingency planning, (e) precise timing of major events in the intubation sequence among different emergency and elective tracheal intubations, (f) subjective assessments of decision-making, teamwork and communications during tracheal intubation and induction of anesthesia.

6.3.5 Categories of Data Available

Through the efforts of videotaping and post-videotaping data collection, we accumulated the following categories of data:

- Video recording.
- Patient physiological data. These data were overlaid on top of the video images (with separate data files). The patient physiological data enabled us to evaluate the resuscitators' activities against normative procedures and to determine if the course of action taken was warranted or if alternatives should have been considered.
- Physician's physiological data. We collected anesthesia care providers' blood pressures and heart rates with ambulatory monitoring devices in more than 20 cases. These physiological data were used to examine the effect of stress and to assess the reliability of subjective ratings of stress.
- Transcriptions of verbal communications captured on video tapes.
- Communication codings. The codings of communications occurring during resuscitation.
- Subjective ratings of stress. Subject matter experts (SMEs) have reviewed more than 50 cases and provided minute-to-minute subjective ratings of stress on six stressors and one overall stress.
- Task analysis through Questionnaires. A 72-item questionnaire was issued to SMEs during their review of video tapes. The questions asked included performance assessment in individual tasks and errors in decision-making. These data were used in testing the proposed theory of decision-making.

- Case participants also filled in a questionnaire (Post-Trauma Questionnaire) after the completion of the case. This questionnaire gave information on, among other items, interaction qualities of the team, the related experience of the participants and fatigue levels.

Stressor	Descriptions
S1: Noise	Auditory noise, which included verbalization, alarms, equipment noise, radios, etc.
S2: Team interaction	Team compatibility and team spirit, any tension caused by ineffective or inappropriate interactions.
S3: Anesthesia crew interaction	Team management, the division of labor, the efficiency and timeliness with which tasks are getting done.
S4: Time constraints	the urgency with which anesthesia-related tasks need to be done in order to ensure patient safety.
S5: Task workload	the complexity, difficulty, or multiplicity of anesthesia tasks that are to be done.
S6: Diagnostic Uncertainty	the need for diagnostic information that is not readily available.

Table 6.2: Stressors used in the subjective ratings. Each stressor was measured on a 5-point scale, which was labeled by "a lot less than usual", "a little less than usual", "usual", "higher than usual", and "a lot higher than usual". They were referred to during data collection as numerals 1–5.

Chapter 7

Incidents Captured by Video versus Self-reporting

Reports of human error in medicine are, in general, based on retrospective recall of events (e.g., Cooper *et al.*, 1978; Cooper *et al.*, 1984) and focused on injuries suffered by patients. The Harvard Medical Practice Study reported the results of a population-based study of iatrogenic injury in patients hospitalized in New York State in 1984. Nearly 4% of patients suffered an injury that prolonged their stay or resulted in measurable disability (Brennan *et al.*, 1991). These and similar studies have used patient chart reviews to determine adverse events from what is recorded, but these reports may suffer from factual uncertainty, data that cannot necessarily be checked and rationalizations made by the reporters once they were aware of the outcome. Caplan, Posner, and Cheney (1990) showed that knowledge of patient outcome changed peer reviewer's perception of appropriateness of care.

Using the data acquired during airway management for patients with trauma, we could contrast incidents reported by clinicians and captured by videotaping. Cheney, et al (1991) found that inadequate ventilation, esophageal intubation and difficult tracheal intubation were frequent causes of critical events during airway management and the most common mechanisms of respiratory-related adverse outcomes. Among 2046 cases with adverse outcomes from anesthesia examined in the American Society of Anesthesiologists Closed Claims Project (Cheney *et al.*, 1991), 762 (37%) were associated with respiratory events and of these 678 (89%) were problems associated with airway management. In 300 cases with airway trauma, obstruction, aspiration, bronchospasm or pneumothorax (all events seen with increased frequency in trauma patients) the incidence of severe injury (brain damage and death) was 47% [141/300] (Cheney *et al.*, 1991).

The Anesthesia Record is a hand-written form completed by the anesthesia care provider at regular intervals (usually every 5 minutes) concurrently with provision of patient care. This record provides details of the anesthesiology care providers airway management for medical and legal purposes. Recording of vital signs or written comments on this record may be briefly deferred if a higher priority task occurs. The Anesthesia Record prompts the anesthesia care provider to record vital signs every five minutes. It provides spaces to record comments unique to a particular patient's management. Prior Anesthesia Records can be used to plan an individual patient's subsequent anesthetic management.

The Anesthesia Quality Assurance (AQA) process is designed to capture all untoward occurrences some of which result in harm or a poor outcome. The AQA reports are made if the anesthesia care provider enters "yes" in response to the question, "Were there any untoward occurrences?" appearing on the computer record entered for each new patient at the end of anesthesia care. After peer review of the reports, changes are recommended if indicated, to prevent recurrences.

We compared the analyses of performance deficiencies identified on the videotaped record of events with three sources of retrospective self-reports, the written Anesthesia Record, a Post Trauma Questionnaire (PTQ) completed after videotaping, and the AQA reports. The written Anesthesia Record and identification of AQA occurrences are routinely completed on every patient managed by the anesthesia care providers, not just those patients' whose care was videotaped. The PTQ was designed to gather data in association with videotaping. The current study was designed to identify how performance deficiencies in airway management for trauma patients were reported and captured, and to identify the primary cause of such performance deficiencies so that methods could be developed to optimize patient care and prevent errors in management.

7.0.6 Methods

Post Trauma Questionnaire (PTQ)

We requested that each anesthesia care provider who was videotaped complete a 30-item questionnaire (PTQ; described earlier) as soon as possible after the end of the case. The PTQ was a no-fault means of reporting in which the recording of personal opinions was requested. The PTQ had no official status as a medical document; it was designed specifically for gathering data during the time that videotaping occurred and was used for several different aspects of a research project examining performance and decision-making under stress.

Anesthesia Quality Assurance (AQA)

AQA reports were official medical center documents that documented AQA activities for the Joint Committee on Accreditation of Health care Organizations. AQA files of the same 48 cases that were recorded on videotape were analyzed for incidents under the general headings of cardiac, respiratory, equipment and drug-related events.

Anesthesia Record

Each anesthesia record was photocopied (patient identifiers were removed). These were reviewed to determine whether events shown on the videotape were recorded on the anesthesia record.

Video Analyses

Video tapes of the events occurring 10 min before, during, and for 10 min after tracheal intubation were analyzed. In all about 20-25 minutes of videotape for each of 48 cases in which intubation occurred were included. The videotapes were analyzed by one or more subject matter experts (SME's), often with the assistance of a trained graduate research assistant who used the Observational Coding System of Tools (OCS Tools, Triangle Research Collaborative Inc, NC), a commercial video-analysis software package. The SME's were all trauma anesthesiologists who participated in videotaping their own patient management. For this study they only analyzed video tapes in which they did not carry out the patient care. When it was unclear from the videotape and other records what had occurred, the topic was discussed with the anesthesia care providers who were videotaped.

When a task was omitted or a performance deficiency was noted during review of a videotape, the cause was determined by reference to patient vital signs data, together with the written Anesthesia Record made at the time, consultation with SME colleagues, and in most cases an audio-taped interview with the anesthesia care provider who treated the patient. The audio taped interview sought background information about the case management, what happened, the experience of the participant anesthesia care provider with similar occurrences, and factors that may have contributed to the occurrence of the performance deficiency. The SME's also requested the anesthesia care providers to identify possible means to prevent a recurrence.

On the basis of these analyses, the task omission or performance deficiencies noted on videotape review were categorized into failures in training, human factors (equipment design, equipment configuration, work place layout, organizational factors), omission of standard operating procedures, and lack of teamwork.

7.0.7 Results

Rate and Reporting of Problems

Eleven videotapes (23%) showed cases in which 28 independent performance deficiencies occurred during airway management. These were often subtle oversights or shortcuts that did not usually in and of themselves jeopardize the patient. Rather, they were performance deficiencies that lessened the margin of patient safety, including the following failures: to examine the patient; of timely patient vital signs monitoring; to check the mechanical ventilator before patient connection; to adhere to standard operating procedures for airway management during induction of anesthesia and tracheal intubation; or to complete preparatory tasks (preoxygenation, neck stabilization, inadequate intravenous access for the planned surgical procedure). Of these failures, none resulted in an adverse outcome directly attributable to the problems identified on videotape. In two of these eleven cases the patients did die, but death was due to uncontrolled hemorrhage from multiple gunshot wounds to the abdomen, and to the head and neck. How Were These Videotaped Events Captured by Other Reports?

Anesthesia Quality Assurance

There were no entries in the AQA records about cardiac, respiratory, equipment or drug related untoward occurrences among the cases that were videotaped. Except for the two patient deaths that occurred unrelated to the intubation sequence and outside the time frame of video recording, none of the performance deficiencies were identified through AQA review.

Anesthesia Record

Esophageal intubation occurred in one patient and remained undetected for over 6 minutes (Mackenzie *et al.*, 1996b). This was reported on the anesthesia record as 'direct laryngoscopy #1 esophageal intubation'. There was no report of the low level of patient oxygenation or the other two attempts of tracheal intubation. In another patient, bleeding into the airway was noted on the anesthesia record, but the omission of neck stabilization during intubation was not recorded despite this omission causing possible injury to the patient's neck.

Post Trauma Questionnaire

Inadequate preparation of the mechanical ventilator in one case in which the ventilator was incorrectly set, was noted on the PTQ. In another case, when intubation was attempted, it precipitated patient vomiting, and in the same case, a drug was given into poorly perfused muscle. The PTQ included the comments "would not attempt intubation and poor drug absorption with poor circulation". The PTQ completed on the patient with the esophageal intubation (decided above) included the comment "in retrospect would rely on clinical signs of oxygenation rather than monitoring". In another patient in which the ventilator was not prepared, the PTQ noted "everyone thought the other had set the ventilator up". In a patient with an inadequate number of intravenous (IV) access sites for the planned surgical procedure, the PTQ recorded "ensure all IVs in place before start of operation.

The PTQ provided an opportunity for the participants who were videotaped to explain apparent deficiencies in their management. Some of the information provided may have been affected by the knowledge that the videotape record existed, but there were no comments at all about self-consciousness leading to inhibition and performance deficiencies. Indeed, there were videotaped episodes of joking, contentious interactions and non-optimal performance that would be unlikely to occur if the anesthesia care providers were constantly aware of being videotaped. We did, however, note comments on the PTQ about stress factors (e.g., the clinical situation, the constraints of time and work-load, and pressure from other clinicians) which were subjectively felt to have contributed to some occurrences of non-optimal performance.

7.0.8 Discussion

The videotapes each recorded a 20-25 min segment of airway management, but the Anesthesia Record and the AQA reports covered all the essential information of a case that sometimes lasted 15 hours or more. The PTQ, however, only addressed self-reporting of events associated with videotaping and although it was more specific in identifying events and possible solutions for performance deficiencies seen on videotape than the Anesthesia Record, it only identified 5 of the 28 deficiencies. The anesthesia care providers completing the PTQ concentrated on specific issues that they often considered a failure of their own performance (e.g., everyone thought the other had set the ventilator up) rather than identifying the underlying problem associated with having the ventilator alarm continuously when put in the ready-mode before patient arrival.

Videotaping in our trauma center revealed the inadequacy of information collection about factors contributing to problems in emergency medical care. Leape (1994) notes that self-reporting systems have low yields compared to active investigations. He advocates data collection methods that will accurately discover and describe the errors that occur, so that something can be done about errors and injuries. Videotaping of events in the naturalistic environment is such a method. Videotapes taken in this way revealed problems during tracheal intubation that were not detected by the AQA reports, the PTQ form, or the hand-written Anesthesia Records, confirming Leape's belief. We do not think that the gaps in information or problems in our trauma center are unique in occurrence; it is generally considered to be among the country's finest trauma centers. Other trauma centers have used videotaping as a training tool to reduce patient resuscitation times, evaluate performance, and increase adherence to assigned responsibilities and found a similar incidence of performance deficiencies in adherence to Advanced Trauma Life Support protocols (Hoyt *et al.*, 1988).

It was the SME's impression that identification of the causes of these performance deficiencies was greatly assisted by repeated review of the video and accompanying audio recording. Circumstances surrounding the performance deficiency would not necessarily have been revealed without the video and audio recording to focus the discussion about what occurred and how a recurrence could be avoided. The videotapes also provided information on the context of the system problem, thus allowing identification of the predisposing factors that may have been operative at the time. When it was unclear what had occurred, repeated review of specific parts of the videotape with the anesthesia care providers enabled the SME's to test different hypotheses about why the performance deficiency occurred and discuss explanations that could then be confirmed or refuted by viewing the videotape.

All of the participant anesthesia care providers were shown the videotapes of their cases. This ability to review the videotapes in private was considered to be a great asset, as it allowed them to identify their performance deficiencies and make constructive self-criticism of their own performance. Other trauma centers have found videotape review to be useful training tool for individual self assessment (Green *et al.*, 1983; Hoyt *et al.*, 1988). The omission of standard operating procedures identified on video analysis has been addressed by such videotape review and by presentations at the Anesthesia Staff meetings.

Although clinical examination is a simple maneuver, this study found it was often omitted

by the anesthesia care providers or was delegated to a non-anesthesia team member. In one instance, this delegation of clinical examination to a medical student lacking experience in airway management was associated with a prolonged undetected esophageal intubation. The medical student incorrectly determined that there was air entry in the lungs and the anesthesia care providers failed to examine the patient with a stethoscope, the oxygenation monitor failed to produce a signal and ventilation (ETCO₂) monitoring was not used, so the esophageal intubation remained unrecognized. The importance of standard operating procedures such as clinical examination, checking the ventilator set-up before use and ETCO₂ after intubation, are all well known to the anesthesia care providers. Omission may have occurred due to time pressure or other factors resulting in lack of team coordination.

Self-Reports

There are several possible reasons why there were so few self-reports of these videotaped performance deficiencies. One is that the anesthesia care providers have worked in the high-paced environment for so long that they have become tolerant of the problems identified by video analysis of tracheal intubation. Another possible reason is that no adverse outcomes occurred and the AQA review and Anesthesia Record did not identify these omissions or deficiencies. However, the AQA reports are not designed to capture performance deficiencies unrelated to an adverse outcome. Still other possible reasons are that the anesthesia care providers may fail to recall these transient and non-injurious lapses in standard operating procedures in emergency management of a difficult patient. It is also unlikely that the knowledge-based training problems would be self-reported, as these anesthesia care providers were unaware that a deficiency existed until review of the videotape with one of the SME's.

It has been previously observed that AQA tends to be outcome-oriented (Edsall *et al.*, 1992), and the terms of the AQA report used in this trauma center conform to that approach. It has also been noted that the AQA system depends on reports that may have limitations in gathering data (Small *et al.*, 1994). Among those limitations are embarrassment, fear, and lack of awareness that an error has taken place. The AQA system is not specifically designed to seek out what the videotape recorded and it is to be expected that we would find limitations compared to video analysis.

There may be a higher reporting rate of occurrences associated with intubation and possibly other organizational, ergonomic and medical human factors issues if anonymous reporting were encouraged. The Aviation Safety Reporting System (ASRS) operated by the Federal Aviation Administration is such an anonymous system of reporting performance deficiencies. Using ASRS, an incident can be recorded and analyzed without the pilot being blamed. However, if an accident or a serious infraction of regulations occurs, the pilot is reprimanded. The ASRS reports are fed back to the airline community as "Alert Bulletins".

The Anesthesia Patient Safety Foundation, an organization dedicated to improving safety during anesthesia, has drafted a position paper modeled on ASRS (D.M. Gaba: Personal Communication, 1994). If this was introduced nationally, through educational anesthesia societies, it would enable anesthesia care providers to report performance deficiencies without fear of legal reprisal. The Australian Anesthesia Incident Monitoring System

(AIMS) is such an anonymous reporting system implemented for the capture and analysis of anesthesia incidents (Webb *et al.*, 1993). An extensive analysis of 2000 incident reports was published in 1993 as a symposium (Runciman *et al.*, 1993). Nearly 4000 reports have now been received from 17 different countries using a standardized reporting form (R. Webb: Personal Communication, 1995). A recent addition is the Anesthesia Critical Incident Reporting System (CIRS) available as an Internet-based reporting system at the University of Basle, Switzerland, (D. Scheidegger. <http://www.medana.unibas.ch/index.htm> - select CIRS). Anonymous reporting is important because in medical performance deficiencies it is the individual that is investigated, and such a system tends to discourage self-reporting.

It is easy to criticize the performance of people dealing with difficult and uncertain situations where even good decisions carry a potential risk (Reason, 1990). The videotapes analyzed in this study show, in the majority of instances, exemplary airway management and skilled creative responses to unusual events that occur with relatively great frequency in emergency trauma patient management. Nonetheless, the fact that these performance deficiencies occurred at all suggests the value of considering ways to avoid exposing patients to such unnecessary risks. One way is for industry to design equipment from the user's perspective, i.e., with consideration of the stresses and environmental factors impacting on the user.

The findings from this study have been presented to the anesthesia care providers at Anesthesia Staff meetings, and recommendations made that standard operating procedural checks should be more rigorously carried out. Clinical examination should occur after tracheal intubation and be repeated after institution of mechanical ventilation. These checks ensure a redundancy of confirmatory signs that the patient is adequately oxygenated and ventilated.

Teamwork Training may be improved by Cockpit Resource Management (Helmreich, 1984) or Anesthesia Crisis Resource Management training (Gaba *et al.*, 1994). In addition, standardized communication procedures in the sequence of tracheal intubation and minimizing the distraction and noise caused by non-task related conversations may be helpful (Mackenzie *et al.*, 1996b). The Federal Aviation Administration stipulates that non-essential conversations be avoided for flight crew members during take-offs and landings (Federal Aviation Regulations, Part 135:100—Flight Crew member Duties, 1995). A similar requirement may prevent distractions during checking of correct placement of the tube in the trachea and confirmation of function of the mechanical ventilator and the reduced noise level may make monitor alarms more easily heard.

Chapter 8

Systems Factors Influencing Decisionmaking

When decisionmaking is considered in the context of a work environment, many factors influence decisionmaking performance. Among these are the factors that are inherent in the work environment. We examined two: (1) workplace layout and (2) auditory alarms.

8.1 Workplace Layout

8.1.1 Introduction

The Trauma Resuscitation Unit (TRU) in a shock trauma center is the first place that the center's staff encounters critically ill patients. In this area patients are resuscitated, stabilized and evaluated for further treatment, surgery or release. The TRU bay is relatively small and there is a wide variety of medical instruments needed for the various tasks performed in the bay. The layout of items in the TRU bay can either help or hinder the working efficiency of the TRU staff. In emergency situations, placement of items used in critical tasks can greatly affect the speed of performance of these tasks.

Placement of items within a workspace is a compromise between human factors, the task to be performed in the workspace, and the physical constraints of the environment. An obvious goal in placement of objects in the workspace is to find a location that would serve all these factors equally well. This optimum layout would maximize the human's strengths while minimizing their limitations. An optimum layout would place all the tools required by the task where the user needs them, but not where they would get in the way when they are not needed. The workplace would be large enough to prevent clutter, but small enough to be comfortable. And best of all, gravity's limitation need not apply. This however, is rarely possible.

In order to balance these often opposing goals, principles of layout have been developed. Sanders and McCormick (1987, Ch. 13) suggest four principles of workspace layout (Importance, Frequency of Use, Functional, and Sequence of Use Principles; see Table 8.1) that guide the placements of items according to the task for which the workspace is intended.

Sanders and McCormick (1987) suggest a number of measures that are necessary for the evaluation of item placement in a workspace. Observing task performance in the workspace is critical to this evaluation, and both the frequency and importance of each item's use should be noted. With this information, the relationships between items, called links, can be examined. Information such as whether Item A is used before or after Item B are valuable in gauging the workplace's adherence to various principles of layout.

Previously, a few methods for evaluating this data have been suggested. Huebner and Ryack (described in Sanders & McCormick, 1987) used linear programming to find the arrangement of eight gauges that lead to an optimal combination of speed, frequency and accuracy. Any layout could be described as a deviation from this optimum layout. Bonney and Williams (1977) developed a computer program called CAPABLE that combines frequency of use and importance information data in order to find a layout that maximizes adherence to the four principles of layout. Layout Appropriateness is a usability inspection method developed by Sears (1993) to measure the efficiency of widget placement in computer interfaces. In Layout Appropriateness, the most efficient interface is the one requiring the shortest movement to perform common tasks. Layout Appropriateness measures the deviation from the optimal placement of computer interface objects.

The methods proposed by Huebner & Ryack, Bonney & Williams, and Sears share a weakness that prevents their use in a complex workspace like the TRU bay. These methods rely on the identification of an optimal, or near optimal, layout against which all options are measured. In workspaces with few items the optimal layout may be possible to identify. The linear programming example in Huebner & Ryack deals with eight items that can be arranged in eight factorial (or 40,320) possible combinations. In complex workspaces like the TRU bay, 40 items may need to be located in a small area for use by an anesthesiologist for a single task. That could lead to 40 factorial possible layouts that must be examined to locate an optimal layout! Because of the complexity involved in many tasks, layout appropriateness restricts itself to the placement of a small number of items in simple environments. CAPABLE on the other hand, employs a rule based heuristic to find a possible optimal layout without testing all layouts. Even with this approximating method, evaluation of complex workspaces remains a difficult, if not impossible, task.

Technical difficulties aside, methods that seek to establish an optimal layout are suited to the creation of new workspaces rather than the improvement of current workspaces. There are many situations in which the current layout already addresses many problems, and an incremental improvement is needed to either allow a new task to be performed in the area, or to modify the layout to improve performance in a very important task. A measure that allows comparison to the current layout, avoiding the complexity of optimum seeking methods, is preferable.

One method that is not based on an optimized solution was proposed by Banks and Boon (1981). Their Index of Accessibility combines frequency of use, the operator's reach, and distance of an item from the operator to assign a score to any layout. This method is far less complex than the methods previously mentioned, but it fails to address the sequence of use principle that Fowler's (described in Sanders & McCormick, 1987) data shows to be most important. A method based on links is required to measure this principle.

Workspace Appropriateness (WA) is a form of link analysis that is fine grained as well as quantitative that measures the relationship between the distance separating linked items and their importance. In this section we attempt to:

- Describe an adjustment to the layout of the TRU bay;
- Show how WA is used to gauge the impact of this design decision on the performance of a crucial task, tracheal Intubation; and
- Verify that the layout changes to the TRU bay have improved satisfaction with the bay without adversely affecting its usability for a vital task, airway management.

8.1.2 Experiment 1: Initial Design

Method

Subjects Nine Anesthesia Care Providers (ACPs), nine nurses, and 17 surgeons who work regularly in the TRU bay were surveyed about their experiences in the TRU bays. Four of the ACPs and an additional seven nurses volunteered to participate in the critique of a new bay design.

Materials and Procedures Based on interviews conducted with representatives from each division, an open ended questionnaire was developed and distributed widely to the TRU Staff. The questionnaire asked: 1.) If there are particular pieces of equipment that interfere with the performance of their job, 2.) If there are particular items that they would like faster access to, 3.) If they can recall specific instances where vital information was not available to them, and 4.) If there are specific pieces of equipment that are not reliable. Performance in the TRU bays was also observed directly and indirectly using videotapes of cases in the TRU bay.

Results

Comments from all subjects suggested that three problems most affect patient care:

- A barrier of tubes and wires limit access to parts of the bay and the patient. Lines radiate out from the patient at all angles, increasing the chances of accidental disconnects.
- The ACPs have difficulty seeing vital signs monitors and ventilator settings while engaged in patient care. These items are either mounted behind their heads or in front of them pointed in the wrong direction.
- Crowding is a serious problem for the staff. Up to 23 people can be found in a four by five meter space. This does not include equipment, supplies, or the patient. Lack of mobility only exacerbated this problem.

Figure 8.1 shows the current layout of the TRU bay while Figure 8.2 shows the new layout of equipment in the TRU bay devised to address these problems. The ventilator was moved to a position at the ACP's right where it can be viewed along with the vital signs monitor. This position allows the various tubes and wires to be concentrated into a single location that leave the rest of the bay open to staff movement. In addition, this layout is consistent with the operating room's ventilator placement.

Importance Principle	The degree to which the item is vital to the achievement of the task. Important items should be placed more conveniently.
Frequency-of-Use Principle	The frequency with which each component is used. Location should be a function of frequency of use. An arrangement should provide for the grouping of
Functional Principle	components according to their function. Items used for the same task should be located together.
Sequence-of-Use Principle	Patterns of relationships between items occur while performing tasks. Items should be arranged to take advantage of these patterns.

Table 8.1: Principles of Layout (Sanders & McCormick, 1987)

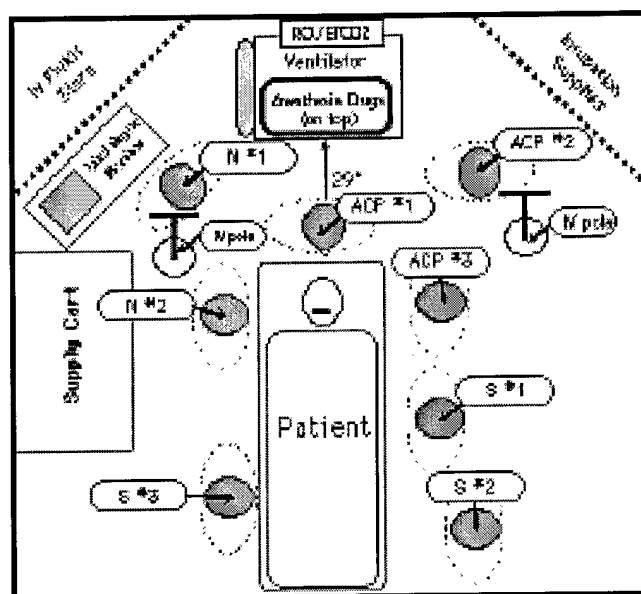


Figure 8.1: The current TRU bay layout with a standard compliment of staff. The ventilator placement in this layout requires the ACP to reach behind their back for equipment and information needed in airway management.

8.1.3 Experiment 2: Layout Efficiency

Method

Subjects Stationary video cameras positioned in two bays of the TRU (Mackenzie *et al.*, 1995) recorded the actions of ACPs performing airway management for nine trauma cases. An additional four ACP subject matter experts judged the importance of each item used for the task of tracheal intubation.

Materials and procedures Link Recording: Links were collected by coding the primary ACP's interactions using a computer coding system and tapes of nine cases of tracheal intubation in the TRU bay.

Item Importance Questionnaire : Item importance questionnaires were completed by four subject matter experts who were faculty anesthesiologists. These experts rated the anesthesia equipment in the TRU bay with regards to their ability to perform a resuscitation in the absence of various pieces of equipment. The questions incorporated a 10 point scale anchored at both end points and a middle score. For example, the question pertaining to the laryngoscope was anchored at its high point by the phrase "vital in every case", in its middle by "vital in some cases", and at its low point by "useful but not vital". Link importance was defined as the mean of the importance scores for the two items in the link.

Each item used, its location, the hand used, and the duration of use was recorded. These events were grouped into links between items. A total of 566 links were recorded. The location of each item in the link was coded, and the distance between these locations was measured in the TRU bay. Distance between items that are mobile were recorded the center of their total range of movement. Some links were between items at a specific location or repeated contact with a single item and were coded as having zero length. Links between the ACP's hands indicating items being shifted from hand to hand were not considered. Another set of links, items that were handed to the ACP, also were not considered because their distance could not be measured accurately. Link distances recorded in any of the observed bays were general to all bays because they are of identical size, and equipment placement is standardized.

The link importance and distance scores for the collected links were used to create a WA score for the current bay. The WA score is a measure of relationship between link importance, measured with the item importance questionnaire, and the link distance. Statistical measures of relationship generally measure deviations from a linear model of perfect relatedness. WA measured in real environments lead to maximum scores, with regard to inter-item distances, that fall substantially below the unconstrained perfect score of a linear model measure.

Using a simple correlation as a measure of relatedness in an unconstrained environment would yield WA values between +1 and -1. A WA score of -1 would indicate an ideal setup where links with the highest importance rating have short link distances. In a real environment though, ideal layouts will yield ideal WA scores that are significantly lower than the available maximum. For this reason the total range of WA scores is constrained and dependent on the individual workspace. It is inadvisable to draw conclusions about the magnitude of WA scores across workspaces. Directional conclusions (this layout is

better/worse than the current layout) can be drawn when several scores are calculated for the same workspace. Magnitude judgments can be made when more than two options are considered (Option A is twice as efficient as Option B when compared to the current layout.)

Results

The observation of nine cases yielded 566 links between 25 items. The frequency of each link varied between 1 and 13 occurrences. Link importance scores ranged from 2.2 to 9.0 with a mean score of 7.4 and standard deviation of 1.1. The agreement between the four raters using the Kendall Rank Correlation ranged from 0.29 to 0.53 with each agreement significant ($p < 0.05$). Link distances ranged from zero to 230 cm. The correlation between link importance ratings and link distances for the current bay was -0.025. By substituting new link distances that reflect the updated bay layout in place of the current link distances but holding link frequency and importance constant we can predict efficiency of performance in the updated bay. The updated bay received a more favorable workplace appropriateness score of - 0.107. This difference supports the hypothesis that the TRU bay redesign will improve efficiency for the task of airway management.

8.1.4 Experiment 3: Satisfaction Measure

Method

Subjects: Nine ACPs, nine nurses, and 17 surgeons completed a subjective satisfaction questionnaire measuring satisfaction with the current bay layout. An additional 14 ACPs completed a satisfaction questionnaire after working in the revised bay layout.

Materials and procedures Subjective satisfaction questionnaire. The subjective satisfaction questionnaire consisted of 17 ratings scales and six directed comment areas rating the current resuscitation bay (see Figure 8.3). A questionnaire containing 13 of the original questions and another five questions measuring the ease of access to particular pieces of equipment was used to measure satisfaction with the subsequent bay layouts (see Figure 8.3).

Subjective satisfaction questionnaires were then distributed to 35 nurses, surgeons and ACPs working in the TRU bays. The updated layout was implemented in a single TRU bay where 14 ACPs completed the subjective satisfaction questionnaire after performing emergency intubation in the bay. These scores were compared to the satisfaction scores of the current bay layout.

Results

The mean satisfaction scores for all groups fell below the goal level of 7.0 on a scale of one to nine (See Table 8.2) with the ACPs expressing the lowest satisfaction. Although the ACPs were generally less satisfied than the rest of this sample, both nurses and

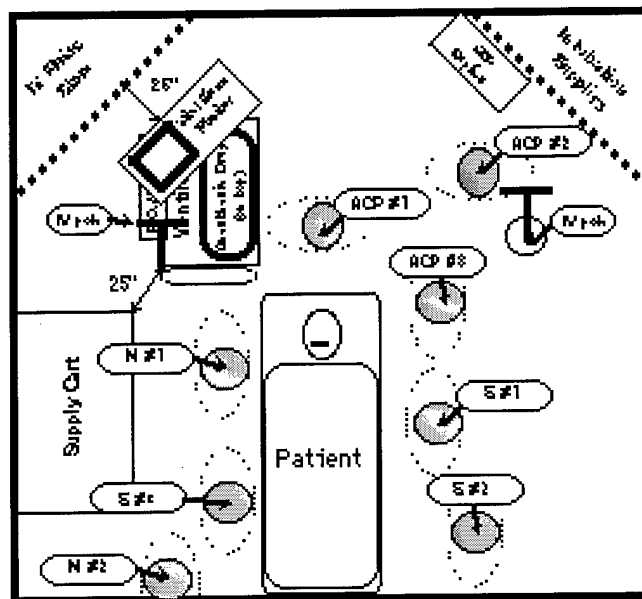


Figure 8.2: The updated TRU bay layout moves the ventilator and monitors into the work area while concentrating tubes and wires into a corridor between the ventilator and patient.

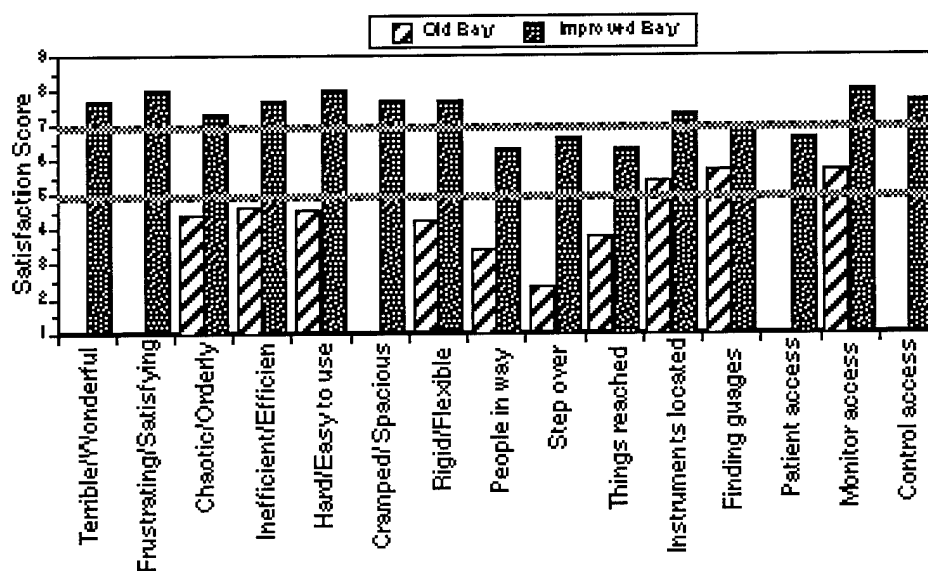


Figure 8.3: Comparison of subjective satisfaction scores before and after update. The older bay setup generally scored below the minimum satisfaction rating of five, while the improved bay layout surpassed this level and often rose above the goal level of seven.

Four Worst Ratings		Four Best Ratings	
You have to setup over wires and tubes	2.3	The vital signs monitor reliability	7.6
People are in your way	3.4	Equipment is reliable	7.4
Things that you need can be reached	3.8	Requests made to you are clear	6.7
General (Rigid or Flexible)	4.2	General (Equipment level)	6.7
People are in your way	3.7	The vital signs monitor reliability	7.8
You have to step over wires and tubes	4.6	Equipment is reliable	7.2
Members of the team work together	5.4	General (Equipment level)	6.7
General (Rigid or Flexible)	5.6	Instruments can be located	7.0
You have to step over wires and tubes	4.2	Bays are prepared for your use	8.3
People are in your way	4.7	The vital signs monitor reliability	7.9
General (rigid or Flexible)	4.7	Equipment is reliable	7.7
Finding patient information	5.8	Requests to you are clear	7.7

Table 8.2: The four best and worst rated areas of the TRU bay divided by specialty. A number of the questions (7, 8 and 5) are consistently rated as poor by nurses, surgeons, and ACPs. Other areas, primarily related to the reliability and functionality of the equipment in the bay, were rated consistently high. ACPs Mean = 5.1 out of 9.0. Nurses Mean = 6.2 out of 9.0. Surgeons Mean = 6.9 out of 9.0.

surgeons had areas of active dissatisfaction. Specifically, limits to mobility, both human and equipment, cause the greatest dissatisfaction in the TRU.

Two questions that measure equipment accessibility and patient access were used to compare the usability of these aspects of the bay layout with the current bay and the updated version. The question that asked about the need to reach over tubes and wires showed a significant increase in satisfaction with the updated layout using the Mann-Whitney U (mean rank(current bay)= 8.2, mean rank(updated bay)= 14.4. $U=29.0$; $p < 0.05$). Similarly, the question asking about the need to step over tubes and wires produced a significantly higher score in the updated bay (mean rank(current bay)= 7.4, mean rank(updated bay)= 15.0. $U=21.5$; $p < 0.05$). This result suggests that the mobility problems of the current bay were effectively addressed without, as the WA score suggests, harming other areas of usability.

8.1.5 Discussion

"Probably the most common method of arranging components by using link data is through trial and error." -Sanders and McCormick (1987)

The goal of this evaluation tool is to predict whether a new design would be better, the same, or worse than the current design. This type of information is useful in making incremental improvements in a workspace that, due to human and environmental constraints, is far from optimal with regards to the four layout principles. The TRU bay suffers a number of constraints (small bays, bulky equipment, and rigid placement of some vital equipment) that allow for only incremental changes to bay layout. WA predicted that our improved TRU bay layout improves efficiency for the anesthesia workspace (see Figure 8.4). The agreement between user satisfaction measures, usability experts judgments, and WA scores suggests that WA is an effective measure of one facet of usability. The predictive and linear response of WA suggests that this measure has construct validity.

A number of other link analysis methods have been used in the evaluation of medical environments. Some studies coded only the movement of the resuscitation staff within the room, allowing the detection of general (both tactile and visual) interactions of the medical staff with equipment (Smith *et al.*, 1993). This approach is difficult to apply to the Anesthesia Care Provider's domain in the TRU. Unlike the environment studied by Smith, *et al.*, the TRU bay is too small to allow the ACP to move freely in the workspace. Subsequently, items used in resuscitation by the ACP are located within a close radius of the head of the bed. A measure of general movements of the ACP fails to identify actions during intubation when the ACP is primarily stationary. Other approaches using eye tracking (Boquet *et al.*, 1980) or time-lapse photography (Kennedy *et al.*, 1976) have been used but yield similar coarse grained results. These methods, although useful for basic research, are not directly applicable for ergonomic evaluation.

A qualitative view of the link analysis data gave an interesting look at the behaviors that the TRU staff developed to deal with usability problems. Because most of the equipment used in intubation is not within quick reach of the ACP, an assistant placed the equipment most likely to be needed around the patient's head and chest, and the primary ACP would take items from this cache of supplies. This crutch for a major ergonomic problem caused its own problems. First, the patient is an unstable platform upon which to place small objects. Secondly, this method requires the presence of yet another person in an already crowded bay. Finally, the placement of items on and around the patient is not at all consistent. This leads to the ACP searching for equipment during a time-critical procedure. This compensatory behavior is important to note because it suggests that we are measuring some abstraction of the TRU bay layout and that the actual bay, without these strategies, would score much worse.

Finally, WA serves a predictive role in workspace evaluation, predicting the effects of layout changes before those often expensive changes are implemented. By inexpensively testing a number of options a wider array of possible solutions to usability problems can be examined quickly without spending the time and expense of user testing on each possible organization. Although this measure does not take every constraint into account, WA reflects one aspect of a complex environment. Multiple measures of behavior are key to this type of analysis because only the convergence of qualitative and quantitative measures reflect the construct of usability.

WA is a tool that predicts the improvement or decrement in task efficiency produced by a layout change. It should be used in situations where efficient task performance is crucial and must not be degraded for the sake of other concerns. Emergency medicine and

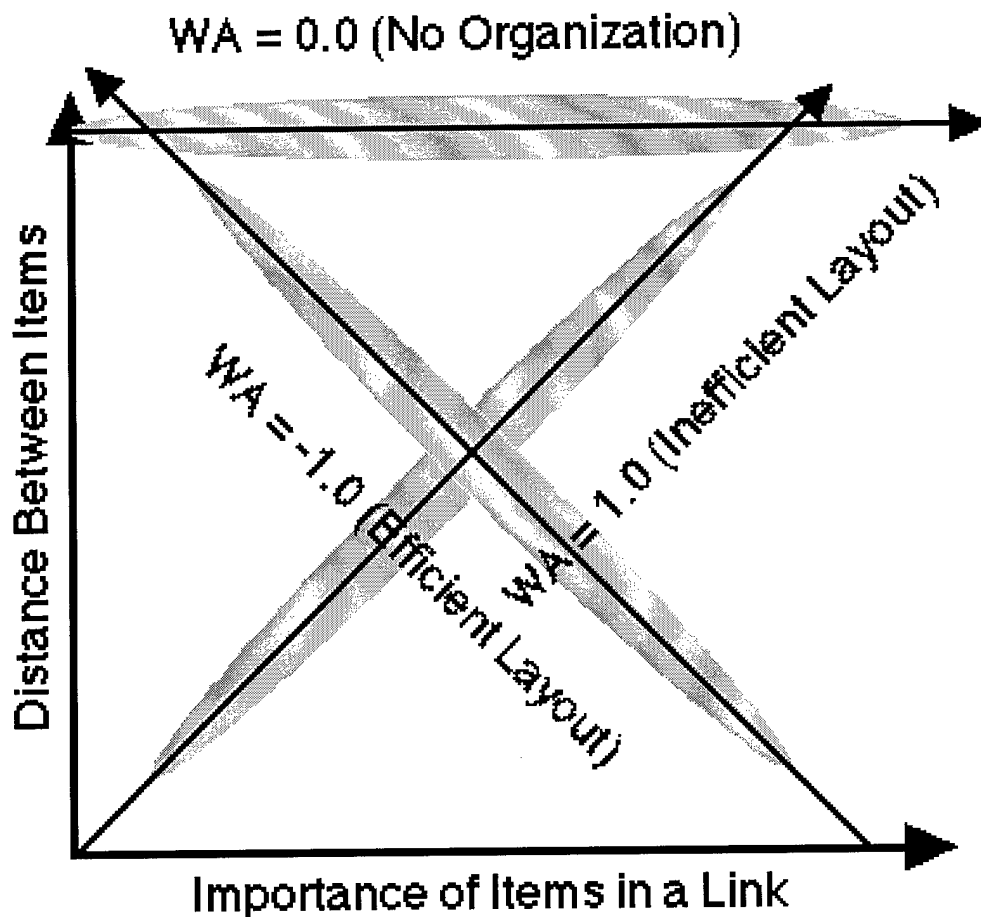


Figure 8.4: The Workspace Appropriateness score. High link importance values correspond to short distances. Because the placement of objects in many workspaces is constrained, Workspace Appropriateness scores tend to be grouped around the center point of this scale, 0.0. An ordinal interpretation of Workspace Appropriateness scores (i.e.; Layout B is more efficient than Layout A) is more applicable than a magnitude judgment (i.e.; Layout B is 34% more efficient than Layout A)

aviation are fields where task performance is crucial and may not be sacrificed for other less important reasons. In situations where "trial and error" design decisions can have dire results, an effective method for modeling the spatial aspect of task performance, such as WA is required.

8.2 Auditory alarms

Problems associated with alarms have been identified (Weinger & Englund, 1990), yet little empirical data exists examining the extent of the problem. We attempted to quantify the use of alarms during emergency and elective airway management, a period of heavy workload and frequent alarms partly due to the transition from masked to mechanical ventilation. We hypothesized that 1) the more alarms occur from a device that are silenced, the more that device's true alarms will be missed, 2) the more false alarms from a device, the more frequently and sooner that device's alarms will be silenced.

8.2.1 Method

The activities of two types of auditory alarms—mechanical ventilator (Servo 900C) and CO₂ /pulse oximetry monitor (Nelco, ETPO) alarms—in video taped real-life airway management cases were recorded by the start and end time of each alarm and the time of each silencing act. Each alarm was coded as (1) a *false alarm* if it occurred during airway suctioning and laryngoscopy or was caused by poor signal or unused equipment, (2) a *missed alarm* if it was a true alarm but was not treated as such by care providers, and (3) a *silenced alarm* if it was silenced by a care provider. A computer program was written to control and to obtain timing information directly from video cassette recorders, and to enter coding. The period between mask pre-oxygenation before tracheal intubation and successful mechanical ventilation through the endo-tracheal tube was selected for coding. Videotapes of both operating room (OR) and resuscitation area cases were coded (both settings used the same kind of ventilators and ETPO). χ^2 test was used for comparison of numbers of silenced, false, and missed alarms, and *t*-test for comparison of alarm durations.

8.2.2 Results

Forty-seven cases (18 in OR s) were coded, with an average length of 468 (SD=234) sec per case. ventilator alarms sounded in 87% (n=41) and ETPO alarms in 66% (n=31) of the cases. The average total duration per case was 22 sec for ventilator alarms and 163 sec for ETPO alarms (Figure 8.5). The majority of alarms were false (Figure 8.6), but the difference between false ventilator and ETPO alarms was not significant. However, ventilator alarms were silenced 4 times more often and on average nearly 8 times sooner than ETPO alarms, and ventilator alarms were twice as likely to be missed (Figure 8.7).

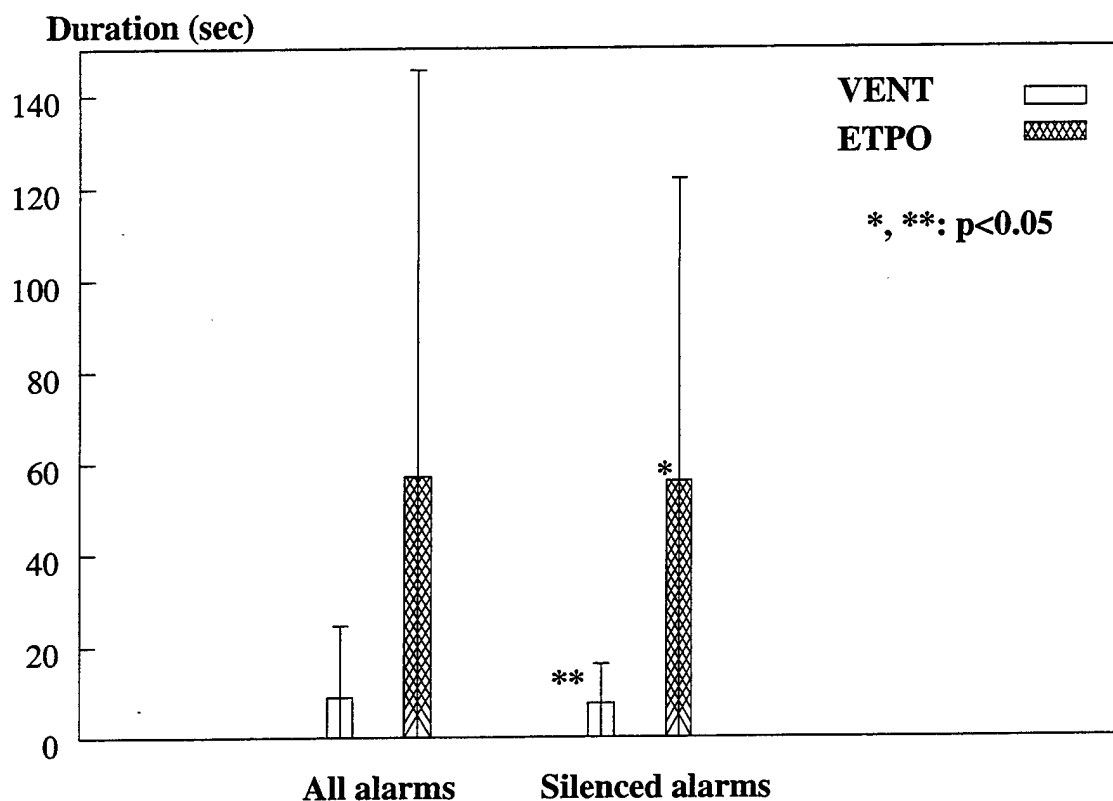


Figure 8.5: The duration of auditory alarms from ventilators and end-tidal CO₂/pulse oximeter monitor. VENT: ventilator (Siemens 900), ETPO: end-tidal CO₂/pulse oximeter monitor. Note that the ventilator alarms were silenced 4 times more often and nearly 8 times sooner than the ETPO alarms.

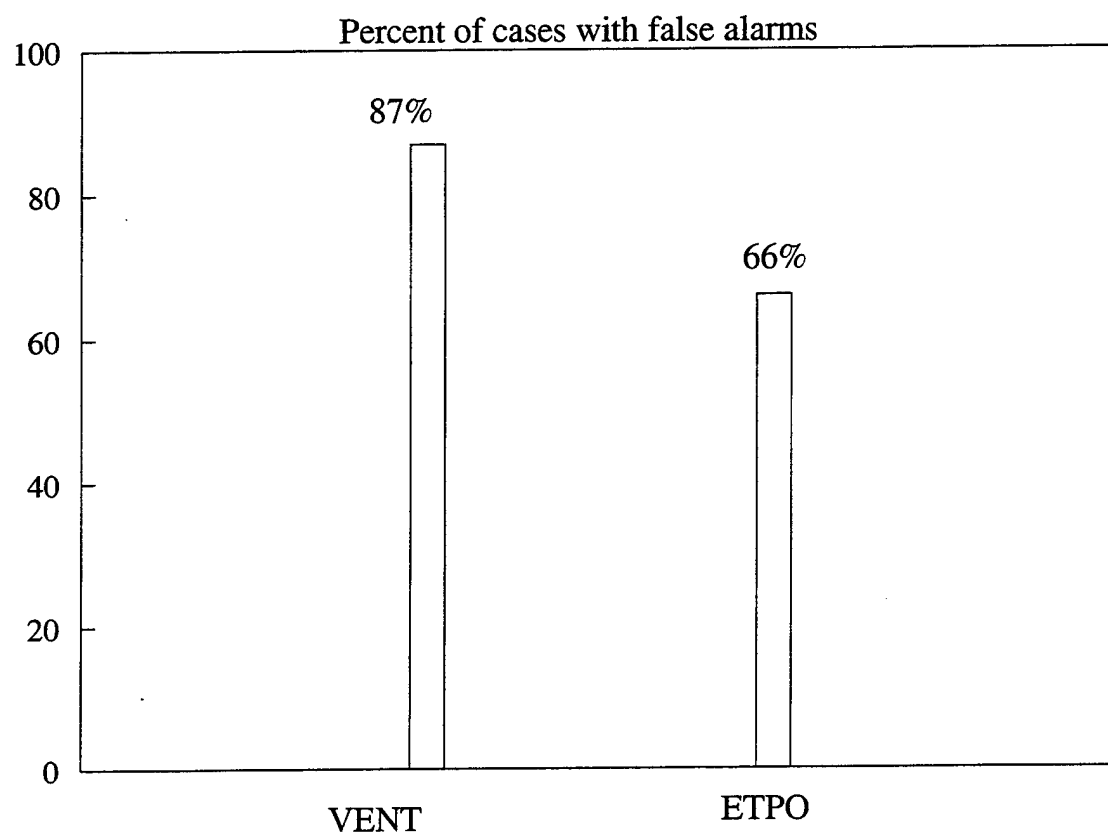


Figure 8.6: The occurrences of false alarms. VENT: ventilator, ETPO: end-tidal CO₂/pulse oximeter monitor.

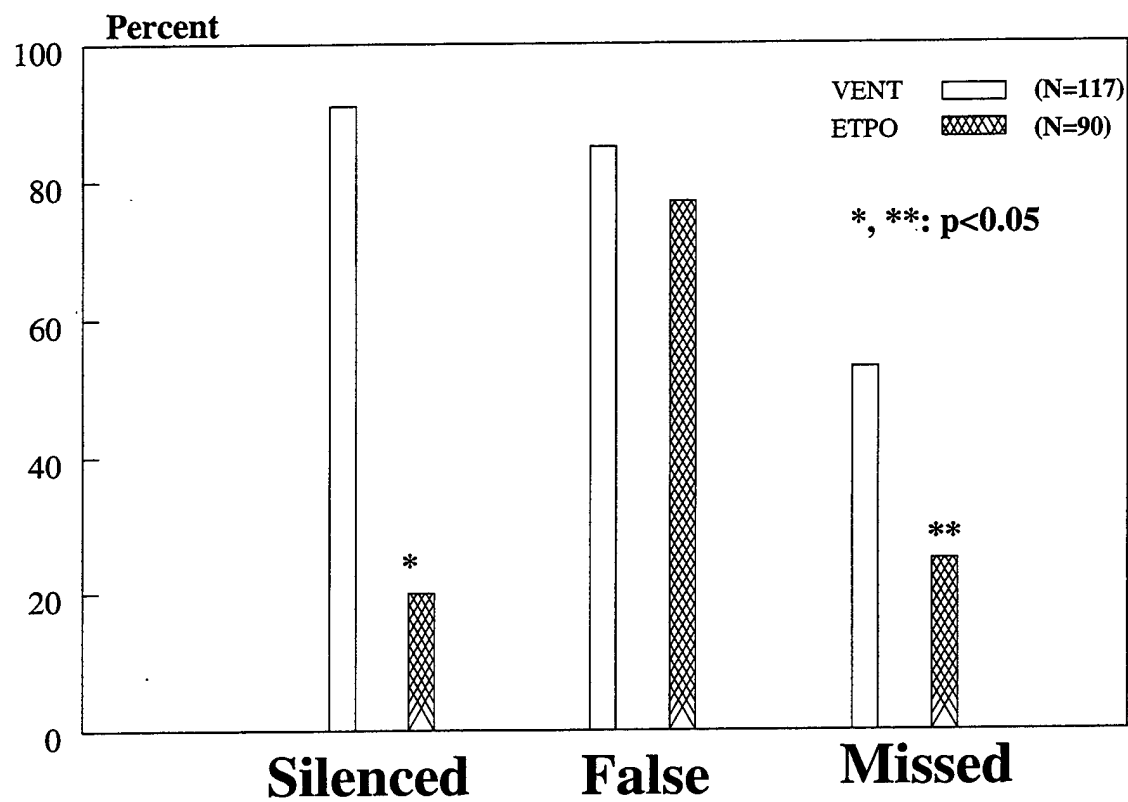


Figure 8.7: The rate of silenced, false, and missed alarms. VENT: ventilator, ETPO: end-tidal CO₂/pulse oximeter monitor.

8.2.3 Discussion

The results support Hypothesis 1 but not Hypothesis 2. The continuous, loud ventilator alarm sound may make it hard for care providers to ignore and probably contributes to the difference in how the two types of alarms were silenced.

The presence of large number of alarms, most of which were false and were silenced, could negatively impact on the quality of patient care. Firstly, the 25–53% of true alarms silenced without investigating the cause of the alarm suggests that false alarms promote the “cry wolf syndrome.” Secondly, the alarms pose extra workload (to push the silence buttons and interrupt the on-going task). Thirdly, frequent occurrences of alarms increase the stress to care providers and distract their attention. Last but not least, auditory alarms produce a noisy work environment which makes it difficult to communicate and to detect other auditory signals.

Chapter 9

Performance Metrics

Based on the data obtained from the Intubation Analysis (IA) forms completed by Subject Matter Experts (SMEs), the task performance by the anesthesia care providers could then be measured.

9.1 Task performance: Are all the steps equally important?

A first question about the task list in Table 6.1 is the relative importance of each task in the list. To obtain a consensus about the relative importance of the tasks in the list, a survey was distributed to the anesthesia care providers. The survey was to measure the relative rank in terms of clinical importance. Table 9.1 is the result of the survey. Note that task relative importance changes slightly when the task urgency of intubation changes.

9.1.1 Task omissions

Using the task analysis questionnaire, the tasks accomplished among the normative intubation task sequence (Table 6.1) could be determined from the videotapes. One of the questions in determining the significance of task omissions is: whether task omissions were due to efficiencies in shedding low priority tasks that could easily be completed at a later, less critical time period, or whether these were errors due to omission of high priority tasks. We hypothesized that such task omissions were efficiencies due to time pressure rather than omission errors due to a failure to carry out important tasks.

The task omissions identified on videotape review were compared before and after weighting with priority rankings. Task omissions were determined as shown in Figure 9.1 as the mean number of tasks not completed divided by the total number of tasks, expressed as percentage. To take into account the relative importance, the task omission rates were weighted by their relative importance scores in Table 9.1.

The results in Figure 9.1 show that the task omission rates dropped after weighting, suggesting that task shedding did occur. However, even accounting for this task shedding, there were still a greater percentage of relatively high priority tasks omitted in preparation for emergency than elective intubations. Thus if our hypothesis were true, that task omissions occurred in emergency intubations because of task shedding, the least

Task names	EL	SE	RE
Pre-Intubation			
In-Line stabilization of the neck	1.90	1.17	1.27
Suction Ready	1.20	1.08	1.25
IV Running Pre-induction	1.27	1.08	1.25
Drugs Given Appropriately	1.18	1.25	1.17
Pre-Oxygenation	1.50	1.17	1.42
Cricoid applied correctly	1.78	1.33	1.25
S _a O ₂ monitored Pre-induction	1.73	1.83	2.33
Heart Rate monitoring Pre-induction	1.73	1.58	2.25
Stethoscope available	1.64	1.83	1.83
Head Positioning	2.20	2.00	2.08
BP monitored Pre-induction	2.18	2.08	2.67
ETCO ₂ monitored Pre-induction	3.42	3.33	3.27
During Intubation			
Intubation equipment ready	1.00	1.00	1.00
Cricoid maintained until ET tube position determined	1.60	1.00	1.08
Auscultation of both sides of the chest	1.33	1.33	1.33
Re-oxygenation if O ₂ sat. <95%	2.00	2.00	2.18
Re-oxygenation after 3 attempts	2.08	2.00	1.91
Tube insertion distance checked	1.92	2.08	2.00
Auscultation of both sides of the chest by the intubator	2.25	2.25	2.17
Auscultation of the upper abdomen	2.08	2.00	1.92
Tube cuff inflated to just seal	2.33	2.42	2.42
Check of neuromuscular block (NMB) before Laryngoscopy	3.25	3.42	3.75
After Intubation			
Check ETCO ₂ within 2 minutes of intubation	1.50	1.25	1.50
Listening to the chest after connection of the ventilator	1.58	1.58	1.58
Tube held till taped or tied	2.42	2.17	2.17
Check of NMB prior to giving the non-depolarizer	2.73	3.00	3.42

Table 9.1: Importance scores for tasks in intubation. Subject matter experts scored the importance on a scale of 1–4, with 1 being the most important and 4 the least important. The scores shown here are the averages across 12 subject matter experts who had extensive experience in the studied center. EL: elective intubation, carried out more than 30 minutes after the patient's arrival at the Shock Trauma Center; SE: semi-emergency intubation, carried out within 10 to 30 minutes of the patient's arrival; RE: emergency intubation, carried out within 10 minutes of the patient's arrival.

important tasks would be shed and we would not expect to detect these differences between emergency and other types of tracheal intubation. We can conclude, therefore, that on average the tasks omitted in preparation for emergency intubations were omission errors not task shedding.

9.2 Comparing Performance of Experts with That of Non-Experts

The results of the completed IA forms from 50 videotapes showing intubation of patients, all of which were admitted to the trauma center, were analyzed to determine if experts performed better than non-experts in the task of intubation. Since a number of cases were reviewed by multiple SMEs, it was possible to assess inter-rater reliabilities. The intraclass correlation coefficient (Shrout & Fleiss, 1979) was used for this purpose.

Intra-rater reliability was assessed on 22 cases which were reviewed by multiple reviewers. Since it was possible that certain cases might be more difficult to the anesthesia care providers than others, we classified the cases into three categories according to the urgency of intubation: emergency, semi-emergency, and elective. These three categories were defined by the elapsed time between the patient's arrival and the start of intubation. They were respectively defined as occurring within 10 minutes of the patient's arrival, 10 to 30 minutes, and more than 30 minutes. The experience of the person who performed intubation (intubator) was measured by the duration of experience: experts were those who had at least 18 months of intubation experience and non-experts were those with less than 2 months of experience. There were no subjects in the collected data who had between 2 to 18 months of experience. The psychomotor skills, number and duration of direct laryngoscopy (DL) attempts, all of which were collected as part of the IA forms, were used as dependent variables.

Intraclass correlation coefficients among different raters were .2–.99 (fair to excellent). There were differences ($p < 0.05$) between expert and non-expert intubators in the duration of the first DL, and the time for DL to cuff inflation after tracheal intubation (Figure 9.2). However, the number of DL attempts was no different (Figure 9.3). Psychomotor skills were subjectively evaluated ($p < 0.05$) among the experts and non-experts and during elective intubations, but comparisons during semi-emergency and elective intubation showed no differences.

The results show that videotaping and video analysis can identify differences between performance of tracheal intubation by experts and non-experts. The lack of difference during performance of semi-emergency and elective intubations may be because the non-experts intubators were closely supervised by an anesthesiologist but the non-experts intubators were given sufficient leeway during elective intubations to allow evaluation of expertise.

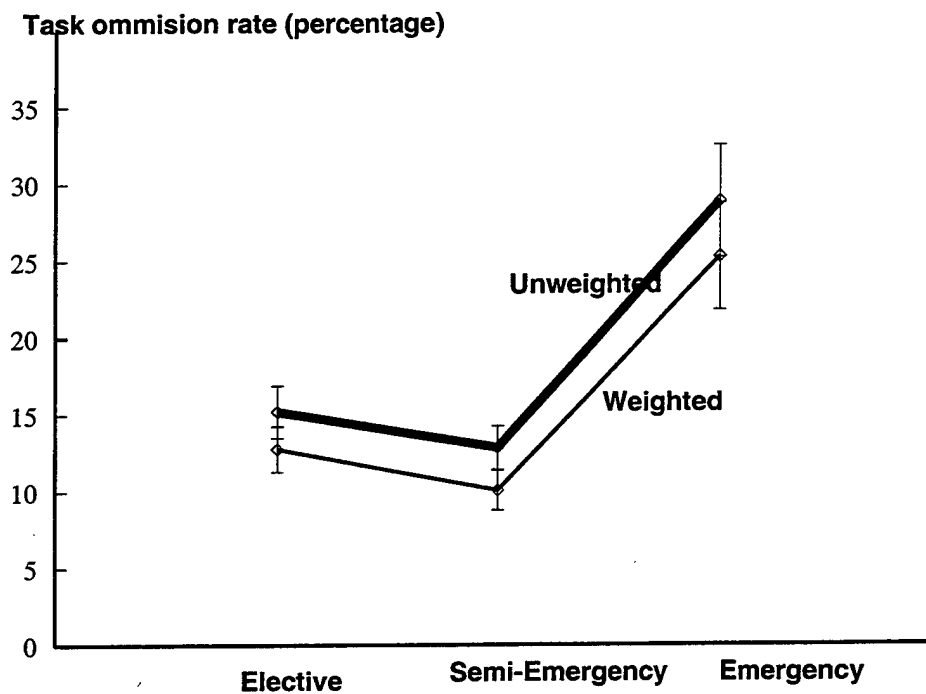


Figure 9.1: Task omission, before and after weighting of importance.

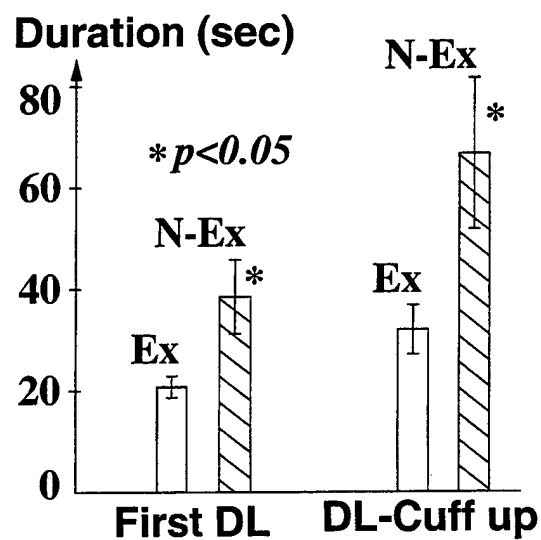


Figure 9.2: Comparison of duration of accomplishing intubation. Ex = expert; N-Ex = Non expert; DL = direct laryngoscopy.

9.3 Comparison of Elective and Emergency Tracheal Intubation

Twenty-three video tapes were analyzed in which eleven patients had elective tracheal intubation carried out in the trauma operating room and the remaining twelve video tapes show emergency tracheal intubation in the trauma patient admitting area. Emergency tracheal intubation was required for life threatening situations including shock (systolic blood pressure <80 mm Hg) (n=3) unconsciousness (n=7) or low blood oxygen levels (n=2). Level of patient injury (assessed by the abbreviated injury score), anesthetic risk (ASA status), and trauma anesthesia grade were no different between the electively and emergently intubated patients. However the Glasgow Coma Scale (assessed level of consciousness) was 15 + SE 0 (=awake) in elective and was less ($p<0.05$) at 9 + SE 0.89 (= impaired) in emergently intubated patients. Figure 9.4 shows the percentage of preparatory items carried out in the elective and emergency intubation sequences from a 12 item check-list before, 7 checks during and 6 checks after intubation. There were significantly fewer ($p<0.05$ unpaired t-test) preparatory checks completed before emergency than elective tracheal intubation.

Subjective assessment of errors and stressors identified no errors in the elective intubations and 6 errors in the emergency intubations. Time stress from surgeons for anesthesia (and therefore surgery) to commence was present in 3/6 elective intubations. Among emergency intubations there were multiple simultaneous stressors including workload, time stress, uncertainty, non-anesthesia team adverse interactions, noise and patient-induced stressors (combativeness, intoxication, etc.). There were errors in drug administration and/or dosages in 3 emergency intubations, two of which resulted during the occurrence of 3 simultaneous stressors (patients #1 and #5), three errors occurred in airway management each of which caused a cascade of detrimental events none of which fortunately adversely affected patient outcome.

The number of physiological monitors in use to provide patient data to the anesthesia care providers was 4 + SE 0.11 for elective intubations and was greater ($p<0.05$ unpaired t-test) than the 2.83 + SE 0.16 monitors in use for emergency intubation. Identical monitoring systems are present in both the trauma operating rooms and admitting areas. Pre-oxygenation before induction of anesthesia (a safety feature to allow less hypoxemia during induction and intubation) was shorter ($p<0.05$) before induction and intubation for emergency than elective intubations (Table 9.2).

Psychomotor skills required to intubate the trachea appeared to be sharpened for emergency intubation. Only one elective intubation required multiple (2) attempts whereas 5 of 12 emergency intubations took a mean of 3 attempts before tracheal intubation was achieved. Despite the greater number of attempts, the time between insertion of the laryngoscope (an instrument to visualize the larynx and allow tracheal tube insertion) and ventilation through the successfully placed tracheal tube was no different (Table 7.1). The duration between tracheal intubation and checking of the correct placement of the tube (by listening to the chest with a stethoscope or looking at the end tidal carbon dioxide (ETCO₂ monitor) was different in elective and emergency intubation. In no elective intubations but in 6 of 12 emergency intubations listening to the chest was delegated to a non-anesthesia team member. This task shedding suggests there was a greater workload associated with emergency than elective tracheal intubation. Monitoring

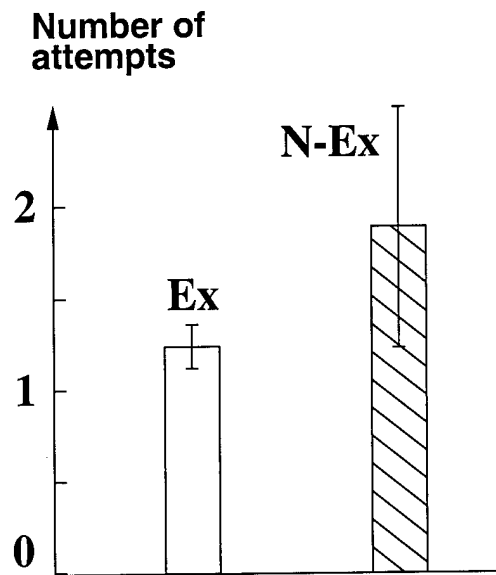


Figure 9.3: Comparison of number of attempts to accomplish intubation. Ex = experts; N-Ex = non-experts.

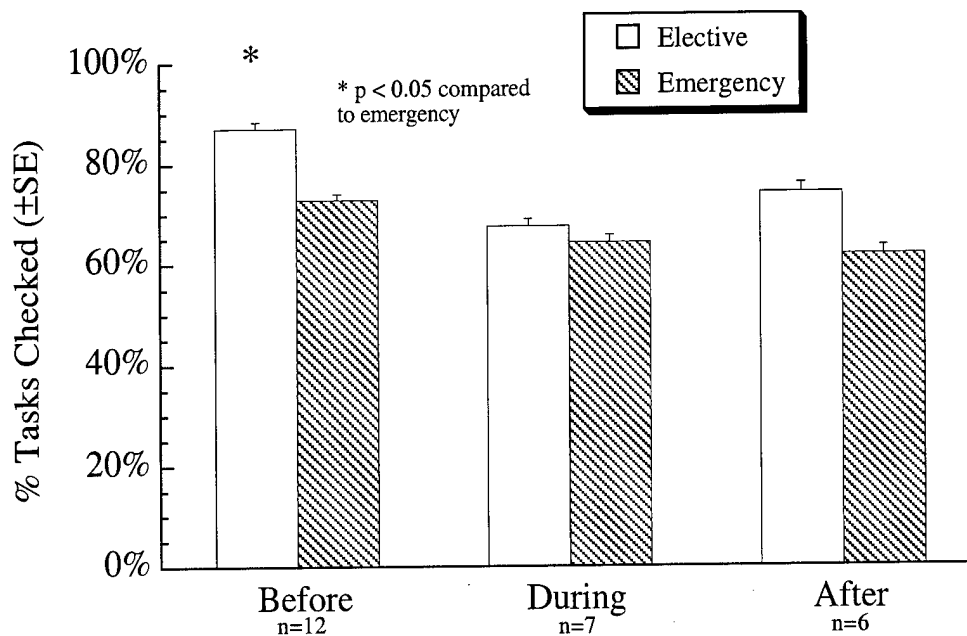


Figure 9.4: Percentage of task completed before, during and after intubation. Three stages were separately analyzed: before, during, and after intubation; two types of intubation were compared: elective and emergency intubations.

of ETCO₂ is a double-check to ensure that transmitted sounds from intubation of the esophagus (when no ETCO₂ is detected) are not confused with breath sounds from ventilator of the lungs. Observation of the ETCO₂ monitor occurred later ($p < 0.05$) after emergency than elective tracheal intubation (Table 1). In one patient (not included in this data) failure to connect the ETCO₂ monitor on ventilation occurred in association with undetected esophageal intubation. Confirmation of correct tube placement is vital to all patient resuscitations so that this delay in observing the ETCO₂ monitors after emergency intubation suggests that task prioritization is inappropriate.

In 5/11 elective intubations but only 1/12 emergency intubations was ETCO₂ monitored before intubation. This occurred because a resuscitator bag is used for initial ventilation in the admitting area during resuscitation and this has no port for connection of the ETCO₂ monitor, whereas an anesthesia circuit (which already includes the ETCO₂ monitor) is used for ventilation in the operating room.

Emergency airway management decision tree contingencies occurred in 5 of 12 emergency tracheal and no elective intubations. In one emergency intubation an event unique to all the participating anesthesiologists occurred; so far this is not described in the literature. At least two other circumstances occurred in association with emergency management of tracheal intubation that are not described in any management algorithms or simulations of emergency airway management.

9.4 Discussion

Video analysis has shown that during emergency airway management task-shedding occurs and short-cuts are taken. Prioritization may also be affected by workload associated with emergency circumstances compared to elective airway management.

Many issues including the failure of ETCO₂ monitoring in the admitting area, the delay in observing ETCO₂, and the fewer preparatory checks completed before emergency intubation are procedural issues that could be improved by training. Much of the uncertainty about patient status during emergency airway management could be reduced by better use of physiological monitors. In addition, some of the errors in management (e.g. esophageal intubation) maybe avoided because of warnings provided by these physiological monitors which are available within arms-reach of the anesthesia care providers. As noted in analysis of pilot errors in the cockpit, problems encountered are often due to the crews failure to use resources that are readily available (Helmreich, 1984).

The video analysis did identify several ergonomic factors which make airway management more cumbersome, and less ideal in the patient admitting area than in the operating room. There is more space and there are fewer people around the head of the patient in the operating room. Patient physiological monitors are placed more conveniently alongside the patient's head next to the anesthesia care providers rather than behind them as occurs in the admitting area. This arrangement in the patient admitting area allows access for patient examination, therapy and diagnosis. The ventilating circuit already contains the ETCO₂ analyzer in the operating room.

The domain of the anesthesia care provider is more clearly defined in the operating room

than in the admitting area, so that roles of the surgeon and anesthesia care provider are more distinct and physically separated. In the admitting area the overlapping roles of surgeons and anesthesiologists (insertion I.V.'s, taking and synthesizing information from the patient's vital signs) can lead to unfavorable interactions and stress among both groups. While the surgeon is the team leader, their expertise does not include emergency airway management. As a result controversies occur over this issue, especially the surgeons failure to appreciate the difficulties and relative risks of one airway management approach over another.

Event	Emergency Intubation	Elective Intubation
Preoxygenation, before aneth.	234 ± 12.5*	92 ± 6.0
Preoxygenation, before DL	310 ± 10.2*	145 ± 6.1
Duration of DL	31 ± 2.1	32 ± 2.4
Duration: DL to ventilate	41 ± 2.5	30 ± 1.3
Duration: Ventilation to Listen to chest	10 ± 0.7	38 ± 5.9
Duration: ventilation to ETCO2 observe	52 ± 5.3*	205 ± 16.8

Table 9.2: Task durations of intubation events. Mean and standard error of duration (in secs) of events in the intubation sequence among 11 elective and 12 emergency tracheal intubation. *: significant at $p < 0.05$.

Chapter 10

Measurement and Prediction of Stress

Three approaches to measurement of stress were attempted in the current project:

- Self-reports at the end of each case. Such reports were sought for their advantage of immediacy in time in relation to the stress experience.
- Perceived stress while reviewing videotapes. Because of the potentially transient nature of stress imposed on the anesthesia care providers, measurement of changes in stress was determined to be critical to the current project. To measure stress continuously, subject ratings of perceived stress were collected while subject matter experts were reviewing videotapes.
- Physiological measurement. To provide data validating the subjective measurement of stress, the physiological responses of anesthesia care providers to stress were measured using ambulatory monitors.

10.1 Post-Case Self-Reports of Stress

A questionnaire (Post Trauma Questionnaire or PTQ) was designed for the anesthesia care providers to fill in immediately after the case videotaped finished. See Appendix 1 for a copy of PTQ.

PTQ were collected from a total of 73 cases. Analysis was carried out to address the following questions regarding the correlation of four variables:

- Did the recall of fatigue level correlate with the hours on duty?
- Did the subjective assessment of case difficulties correlate with the subjective assessment of the stress level felt by the participants?
- Did the fatigue level correlate with stress level?
- Did the patient neurological status, an indicator of how critical the patient condition was, correlate with the stress level felt by the participants?

Table 10.1 display the results.

10.2 Determinants of Trauma Anesthesiologists' Perceptions of the Difficulty and Stressfulness of a Case

10.2.1 Introduction

The factors that affect the perceived difficulty and stressfulness of skilled performance have been studied under contrived laboratory situations for some time. One finds the relevant literature under such rubrics as mental workload, stress and strain, the nature of expertise, and skilled decision-making. Rarely, however, have systematic data been collected in the workplace based on the actual task performance of experts applying their trade. The perceived difficulty and stressfulness of performing a skilled task might be considered to be determined largely by factors that the task environment imposes on the performer. However, further reflection suggests that such judgments more likely are influenced by the interaction of task difficulty, in some objective sense, with certain traits of the skilled performer. Moreover, these traits might include both relatively transient factors – e.g., the fatigue that is existent on a given day, the quality of interactions with ones teammates – as well as less malleable factors – e.g., ones experience in the task domain of interest, personality traits, and individual physical or cognitive limitations.

There are several reasons that it is important to understand the factors that influence self-perceptions of task difficulty and stressfulness. First, these perceptions might be a predictor of the quality of performance or the risk of errors. If so, a better understanding of practitioner' perceived difficulty and stress may, depending on the factors identified, offer guidance in work scheduling, team coordination, or even self-management of ones work schedule. Of course, part of acquiring skill may be the ability to overcome the initially deleterious effects of perceived difficulty and perform quite admirable regardless of the demands of the situation. Second, a better understanding of the variables that affect perceived difficulty and stressfulness may belie the underlying dynamics of information processing and aid in modeling performance in complex environments. Finally, as was the case with the present data, we were interested in the extent to which perceived difficulty and stressfulness may have co-varied or in some way influenced other measures of performance.

In this section, we examined the self-perceptions of trauma anesthesiology care providers (ACPs) treating acute trauma patients.

10.2.2 Methods

The Post-Trauma Questionnaires (PTQs) were completed by 19 different ACPs in the course of 89 cases. The anesthesiologists ranged in age from 29 to 63 years, with an average age of 38.5 years. They ranged in general experience as an anesthesiologist from 2 years, 10 months to 35 years, with an average of 10 years. Finally, experience specifically in trauma anesthesiology ranged from 1 month to 16 years, with an average of 3.3 years.

10.2.3 Data Analysis

One fundamental difficulty in assessing phenomena such as fatigue, experience and injury severity is that there are various underlying components that contribute to these phenomena. It is often difficult to know which aspects of a particular variable are most influential at any given time. Similarly, it is difficult to be certain which aspects of the phenomena are being measured by questionnaire items. With this difficulty in mind, we attempted to construct questions that would probe a specific measure (i.e., fatigue, experience) in different ways. In order to appraise the more subtle aspects of fatigue, experience and injury severity both linear regression and principal component analysis were used to evaluate the data.

Linear regression Linear regression was used to assess the relationship between independent and dependent measures. Because some degree of correlation was expected between the variables, separate linear regressions were performed with each independent variable being regressed on each dependent variable. It was thought this procedure would best reveal the individual relationship between each pair of measures.

Principal components analysis - factor method The Factor Method of Principal Components Analysis of PTQs was employed using the SAS statistical package. Principal Components Analysis (PCA) is a multi-variate technique used for examining relationships between variables thought to be correlated. PCA can be used to determine which of the correlated measures (i.e., measures that share variance) clustered into common factors or components and the number of orthogonal components there are in a data set.

In order to understand the relationship between the PTQ items and the underlying components, first one examines the Eigenvalues and the Proportion and Cumulative values (Table 10.2). Typically, one uses the Eigen greater-than-one rule to determine how many components to keep for further analysis. Essentially, this rule recommends keeping factors whose Eigenvalues are >1 . Then one examines the Proportion and the Cumulative values for each factor. This will show the amount of variance accounted for by each factor separately, and the cumulative variance contributed by each factor.

Next, one examines the Factor Pattern (Table 10.3). The Factor Pattern shows the contribution of each PTQ item to each factor. The PTQ items with the largest factor values contribute the most to that factor. By understanding the commonalities between the PTQ items that contribute most to a particular factor one can begin to interpret the underlying nature of the factor.

By way of example, consider the five Experience measures in the PTQ: 1) years as an anesthesiologist, 2) years managing trauma patients, 3) number of similar cases, 4) recency of similar cases, 5) recency of working with surgical crew. Performing a PCA on these measures shows that there are two underlying components. That is, two components with Eigenvalues greater than one. It also shows that the first component is derived primarily from Experience items a, e and f. This underlying component could be described in terms of 'length of experience'. The second component is derived from items b and d and could be described in terms of 'recency of experience'.

In this way, PCA can be used to reduce the number of variables in a regression equation.

Correlation Pair		N	r	p
Fatigue level	Hours on call	68	0.47	< 0.001*
Stress level	case difficult	73	0.60	< 0.001*
Fatigue level	Stress level	73	0.29	< 0.02*
Stress level	GCS	72	- 0.123	= 0.3

Table 10.1: Stress measured by Post Trauma Questionnaire. The results were pairwise Pearson product moment correlations. Note: there were blank cells in the filled PTQ. In the calculation of Pearson r , these cells were removed.

	FACTOR					
	1	2	3	4	5	6
Eigenvalue	2.33	1.33	.90	.69	.53	.29
Proportion	.39	.22	.15	.12	.09	.04
Cumulative	.39	.61	.76	.88	.96	1.00

Table 10.2: Result 1 of principal components analysis of Stressors. Factor 1 (length of experience) Factor 2 (recency of experience) have Eigen values >1 and were further analyzed

Items	FACTOR PATTERN	
	Factor 1	Factor 2
a.	.75	-.17
b.	-.09	.58
c.	.38	-.68
d.	.37	.68
e.	.82	.19
f.	.90	.04

Table 10.3: Result 2 of principal components analysis. The Factor Pattern shows the contribution of each item in the Post-Trauma Questionnaire (PTQ) to the principal component factors identified in Table 10.2.

This is accomplished by producing component scores, which represent the underlying factors in the data. Since the component scores retain virtually all the information inherent in the original variables, they can be used as predictor variables and regressed on the dependent measures.

10.2.4 Results

The first analysis was a general linear regression; the results are shown in Table 10.9. While there are clearly significant relationships in these data, the irregular pattern of results led the investigators to believe that there may be underlying factors at work. These underlying factors could be contributing in a systematic, but not readily apparent, way to the pattern of results in the linear regressions (Table 10.9). If these factors could be discovered, they may better clarify the relationships between the measures. For this reason, a Principal Components Analysis (Factor Method) was performed and reveals the underlying components for each group of independent measures.

Experience In the Experience items, the Principal Components Analysis revealed two underlying factors (length of experience and recency of experience), thereby reducing the six questionnaire items to a more manageable number. The underlying factors are indicated in Table 10.2 by the Eigenvalues. Using the Eigen's greater-than-one rule we have two independent factors (or components). In Table 10.3, we see the two factors and how they relate to each questionnaire item. The first factor is most strongly related to questionnaire items which reflect the amount or length of experience (e.g., a.= number of similar cases, e.= years as an anesthesiologist, and f.= years as a trauma anesthesiologist). The second component is related to items that reflect the recency of experience (e.g., b.= how long since the anesthesiologist has managed a similar case and d.= how long since working with the surgeon). Table 10.8 shows that Experience Factor two (recency) is significantly correlated with ratings of case difficulty ($r^2 = .49$, $p < .04$). Experience factor two is also significantly correlated with ratings of ones own performance ($r^2 = .49$, $p < .04$). Table 10.8 also shows that Experience Factor two is significantly correlated with Stress ($r^2 = .57$, $p < .04$).

Fatigue In the Fatigue items, the Principal Components Analysis also revealed two underlying factors, this time reducing the five questionnaire items. The Eigenvalues are shown in Table 10.4. Table 10.5 indicates the relationship between the two factors and the questionnaire items. Factor 1 is a combination of questionnaire items which reflect the length of time the anesthesiologist is awake and engaged in task related activities (e.g., b.= number of hours awake, c.= hour of shift when case occurred and e.= hours actively involved in patient care). The second Fatigue factor is primarily based on item d., 'how long ago was your last shift'. The component of fatigue underlying this item may have most to do with the amount of time off, or feeling rejuvenated at work. Table 10.8 shows that Fatigue factor one is significantly correlated with ratings of Fatigue ($r^2 = .56$, $p < .0005$). Fatigue factor one is also correlated to Anesthesiology Team Interaction ($r^2 = .53$, $p < .05$).

Injury severity From the Principal Components Analysis of the Injury Severity items, a single factor emerged. Table 10.6 shows the Eigenvalues for the analysis. Table 10.7 shows the relationship of the questionnaire items to the single factor. This factor is clearly related to three injury severity scales (a. AIS, c. ASA and d. TAG). These three scales have to do with a general assessment of the patients' state, unlike the GCS, which deals more specifically with head injury. In Table 10.8, the Injury Severity Factor is significantly correlated with ratings of Case Difficulty ($r^2 = .53$, $p < .001$).

10.3 Measurement of Perceived Stress

10.3.1 Characterization of Collected Data on Stress

For the period of three years, 42 cases were reviewed by 15 raters in 81 video review sessions, of which 22 were by participant raters and 59 by neutral raters. The numbers of emergency, semi-emergency, and elective intubation procedures reviewed were 16, 12, and 14, respectively. On the average each session contained 22 time points. A total of 1782 sets of ratings were collected, with each set of ratings defined as the 7 ratings on the 7 measured items given by one rater at one time point in one case. Twenty (20) cases were reviewed by multiple raters: 9 cases reviewed by 2 raters, 6 cases by 3 raters, 4 cases by 4 raters, and 1 case by 8 raters. Among the 15 raters, 1 reviewed 27 cases, 1 reviewed 19 cases, and the rest reviewed between 1 to 6 cases. The data distribution among subject matter experts and cases is shown in Table 10.10

10.3.2 Assessment of Interrater Reliability

For those cases with multiple raters, intraclass correlation coefficients (ICCs) were calculated to measure the agreement between raters. Following Shrout and Fleiss (1979), we used the formula $ICC = (BMS - WMS) / (BMS + (k-1)WMS)$ to calculate ICCs, where BMS is the mean square of ratings between time points, WMS the mean square of ratings between raters within time points, and k the number of raters used in a given case. The results are in Table 10.11. There was a wide difference in the perceived stress among the raters, given the low to moderate ICCs.

Several factors could have contributed to the variation in the ratings provided by multiple raters:

- The ratings were collected over a long period of time. The rating strategies of the raters may have changed over time and became divergent.
- Raters had varied personal background. The difference in ratings simply reflected how they perceived stress in different ways.

10.3.3 Factors of Perceived Stress

Several variables were used to determine the important factors of perceived stress. These variables were:

	FACTOR				
	1	2	3	4	5
Eigenvalue	1.99	1.34	.68	.58	.40
Proportion	.40	.27	.14	.14	.08
Cumulative	.40	.67	.80	.92	1.00

Table 10.4: Result 3 of principal components analysis of Fatigue Stressors
Factor 1 (length of time awake) and Factor 2 (time since last worked) have Eigen values > 1 and will be further analyzed.

Items	FACTOR PATTERN	
	Factor 1	Factor 2
a.	.20	-.82
b.	.85	-.06
c.	.84	.04
d.	-.05	.81
e.	.75	.09

Table 10.5: Result 4 of principal components analysis identifies the PTQ items and the factors identified in Table 10.4

	FACTOR			
	1	2	3	4
Eigenvalue	3.11	.51	.27	.11
Proportion	.78	.13	.07	.03
Cumulative	.78	.91	.97	1.0

Table 10.6: Result 5 of principal components analysis of Injury Severity, which identified 3 injury severity scales as correlated with case difficulty. Items in the questionnaire (PTQ) that were correlated with dependent measures are shown in Table 10.9

Items	Factor 1
a.	.30
b.	-.25
c.	.28
d.	.29

Table 10.7: Result 6 of principal components analysis identifies the questionnaire (PTQ) items related to the factor identified in Table 10.6

Component	Dependent Measure	Trend*	r^2	F	p
Trauma Index	Case Difficulty	L	.53	12.53	.001
Fatigue Factor 1	Fatigue	L	.56	14.30	.0005
Fatigue Factor 1	Anesth. Team Interact	Q	.53	4.17	.05
Experience Factor 2	Case Difficulty	L	.49	4.57	.04
Experience Factor 2	Own Performance	Q	.49	4.57	.04
Experience Factor 2	Stress	L	.57	4.36	.04

Table 10.8: Result 7 of principal components analysis. Regression of component scores on dependent measures. *L = linear trend, Q = quadratic trend. This analysis shows that the recency of experience (Factor 2) is significantly related to Case Difficulty, Own Performance and Stress

Independent Measure	Dependent Measure	Trend*	r^2	F	p
Hours Awake	Fatigue	L	.59	17.08	.0002
Hour of shift video began	Fatigue	L	.58	23.40	.0001
Time since similar case	Own Performance	Q	.49	4.66	.04
Number of similar cases	Interaction with Nurses	Q	.65	6.40	.01
Number of similar cases	Stress	Q	.51	4.66	.05
Number of similar cases	Case Difficulty	Q	.47	4.60	.04
Frequency of working with surgeon	Case Difficulty	Q	.46	4.40	.04
GCS	Case Difficulty	L	.45	4.11	.05

Table 10.9: Result 8 of principal components analysis. General linear regressions. *L = linear trend, Q = quadratic trend

Case	9270	8949	733	5243	4967	7308	9350	9630	7337	8277	9498	1186	9628	4310	6951	# SMEs	# Data
5			17													1	17
7			15													1	15
12			50													1	50
16			20													1	20
24		13	13													2	26
32			13													1	13
35		18	14										17			3	49
36		25											20			2	45
38			21													1	21
41			26													1	26
45			20													1	20
50		29														1	29
53								12								1	12
55		25														1	25
57		27														1	27
59			13													1	13
64			25								17					2	42
68			15													1	15
69			18		24											2	42
71		24									25					2	49
72		24	24										18			3	66
73		22														1	22
74		17														1	17
75									10							1	10
76			15												13	2	28
78			60													1	60
79			15				13				20					3	48
81		18	19												19	3	56
82		28				24					11					3	63
83		47							46							2	93
84			17		17		17			17						4	68
86									26							1	26
88		21	39	36			10									4	106
89			22	21			18						23			4	84
90			6											16		2	22
91	12		16							16						3	44
92		14	19			40	17		21			27		10		7	148
95		17							16							2	33
96		48	20				20		24							4	112
102		24														1	24
105		18														1	18
Total	12	459	552	57	41	64	95	12	143	16	90	27	78	26	32		1704

Table 10.10: The numbers of data points of the collected subjective stress ratings. The top row indicates subjects' identification (last four digits of their social security numbers); the left column are the case numbers; SME: subject matter experts.

- Personal experience and individual difference
- Task urgency
- Task stages

Individual Difference in Rating Perceived Stress

For the purpose of determining the impact of personal experience in the case under review, we identified two types of raters: *participant* and *neutral*. Participant raters were involved in the care of the patient in the particular case being reviewed, whereas neutral raters were not. For participant raters, the review occurred within a short time after a case was videotaped, usually within a week.

The Impact of Task Urgency

The *task urgency* was determined by the time between the patient's arrival at the admitting areas and the start of intubation. In the analysis of ratings, the cases were separated into three categories according to task urgency: emergency, semi-emergency, and elective, defined as when the intubation took place within 10 minutes, between 10 to 30 minutes, or more than 30 minutes, respectively, after the patient's arrival at the admitting areas.

Task stages

The task stage were defined as before, during and after intubation. Operationally, before intubation is the period from up to 10 minutes before IV induction to IV induction; during intubation is the period from IV induction to tracheal tube cuff inflation, and after intubation is the period from cuff-up to connection to the ventilator.

10.3.4 Correlations Among the Measured Variables

The 7 measured variables of subjective ratings were found to be highly correlated, as shown by the correlation matrix (Table 10.12). A principal component analysis was performed to further examine the interdependencies among the 7 items. The results (Table 10.13) show indeed a high communality among the items. The first principal component accounts for 65% of the variance in data, and first two principal components account for more than 75% of the variance. These findings suggest that the raters in the study gave ratings more or less on a single dimension.

10.4 Regression Analysis

The six stressors were proposed as potential sources of contributions to the overall stress level. A number of questions remained:

Stressor & overall stress ratings	ICC	SD
Noise	0.17	0.03
Team interaction	0.31	0.02
Anesthesia crew interaction	0.22	0.03
Time constraints	0.30	0.02
Task workload	0.26	0.03
Diagnostic uncertainty	0.36	0.02
Overall stress	0.38	0.02

Table 10.11: Intraclass correlation coefficients (ICCs), calculated based on the definition from Shrout & Fleiss, 1979.

	S1	S2	S3	S4	S5	S6	S7
S1		0.54	0.51	0.54	0.54	0.50	0.60
S2	0.54		0.60	0.50	0.47	0.51	0.53
S3	0.51	0.60		0.61	0.59	0.48	0.60
S4	0.54	0.50	0.61		0.81	0.62	0.79
S5	0.54	0.47	0.59	0.81		0.56	0.76
S6	0.50	0.51	0.48	0.62	0.56		0.75
S7	0.60	0.53	0.60	0.79	0.76	0.75	

Table 10.12: Correlation matrix for the stress ratings from the seven items. S1 to S6 stand for the six stressors described in Table 6.2 and S7 for the overall stress. All correlations are significantly different from zero at 5% significance level.

Components	Eigenvalue	Proportion
1	4.55	0.65
2	0.74	0.11
3	0.54	0.08
4	0.47	0.07
5	0.35	0.05
6	0.19	0.03
7	0.17	0.02

Table 10.13: Results of principal component analysis. The first column is a list of uncorrelated components (linear combinations of the 7 measured variables), the second column is the largest eigenvalue associated with that component, and the third column is the proportion of the variance in the data accounted by the component.

- Are there other stressors that contribute to the overall stress?
- Can the six stressors be used to predict the overall stress?
- Which of the six stressors contributed more to the overall stress?
- Is there a difference in the perception of the relative contribution among the stressors between neutral and participating subject matter experts?
- Do the relative contributions of the six stressors change with the task urgency and task phase change

A multiple linear regression was performed on the following model:

$S_7 = W_0 + \sum_{I=1}^6 W_I \cdot S_I$, where $S_{I=1...6}$ were the subjective ratings of perceived stress for the six stressors (C.f. Table 6.2), S_7 the overall stress rating, and $W_{I=1...6}$ the regression weights for the six stressors. Table 10.14 displays the results of the regression. Task related factors (time constraints, task workload, and diagnostic uncertainty) were weighted higher than were other factors.

A regression analysis was performed separately on those ratings from the participant raters and those from the neutral raters. The results (Table 10.15) indicated significant differences between the two groups of raters in the weights associated with the stressors of noise, task workload, and diagnostic uncertainty. Among the three top ranking stressors, the participant raters weighed task workload more heavily than did the neutral raters. The third stressor with which the participant raters and neutral raters differed significantly was noise. The participant raters attributed noise more to the overall stress than the neutral raters would. Such a difference of view on the contribution of workload and noise to stress may occur because the case participants had an intimate appreciation of the workload involved in and the impact of noise on the reviewed intubation process.

10.4.1 Temporal Profiles of Stress Ratings Over Time

Recall that the tracheal intubation procedures were recorded during real-life performance, and that they had different time lengths and consequently different number of time points for collection of ratings. The aggregation of data across cases was achieved by choosing for each case a single time point as the alignment point. Two alignment points were contrasted: the start point and the success point of intubation. Figure 10.1 displays the resulting temporal profiles of the aggregated ratings for the overall stress. Different temporal profiles of stress occurred when different alignment points were chosen. Subsequent results were all based on the use of the success point as the alignment point.

Figure 10.2 displays the temporal profiles of overall stress (S_7) for the reviewed intubation procedures with three types of task urgency. Figure 10.2 indicates the peak point just prior to the success point for procedures of all three task urgencies. It also shows the upward shift of temporal profiles when the procedure of tracheal intubation became progressively more urgent.

Figure 10.3 shows the temporal profiles of all 7 items included in the measurement scale. As expected from the result that all 7 items in the subjective ratings were highly correlated, parallel increases and decreases in ratings are noted.

Stressors	Weights	<i>p</i>
Noise	$W_1 = 0.113$	0.015
Team interaction	$W_2 = -0.014$	0.015
ACP interaction	$W_3 = 0.067$	0.016
Time constraints	$W_4 = 0.277$	0.021
Task workload	$W_5 = 0.231$	0.020
Diagnostic uncertainty	$W_6 = 0.370$	0.016

Table 10.14: Results of multiple linear regression. Dependent variables were ratings from the six stressors and the independent variable was the overall stress ratings. Multiple correlation coefficient $R^2 = 0.88$.

Stressors	Neutral (n=1307)		Participant (n=475)	
	Weights	Rank Order	Weights	Rank Order
Noise*	0.071	6	0.159	4
Team interaction	0.032	5	-0.010	6
ACP interaction	0.113	4	0.081	5
Time constraints	0.294	2	0.226	3
Task workload*	0.132	3	0.318	2
Diagnostic uncertainty*	0.391	1	0.324	1

Table 10.15: Comparison between the two types of raters (participant and neutral) in terms of multiple linear regression results. *: regression weights associated with the stressor for the two groups of raters were significantly different when compared at 5% level, tested by fitting a single model with interaction terms.

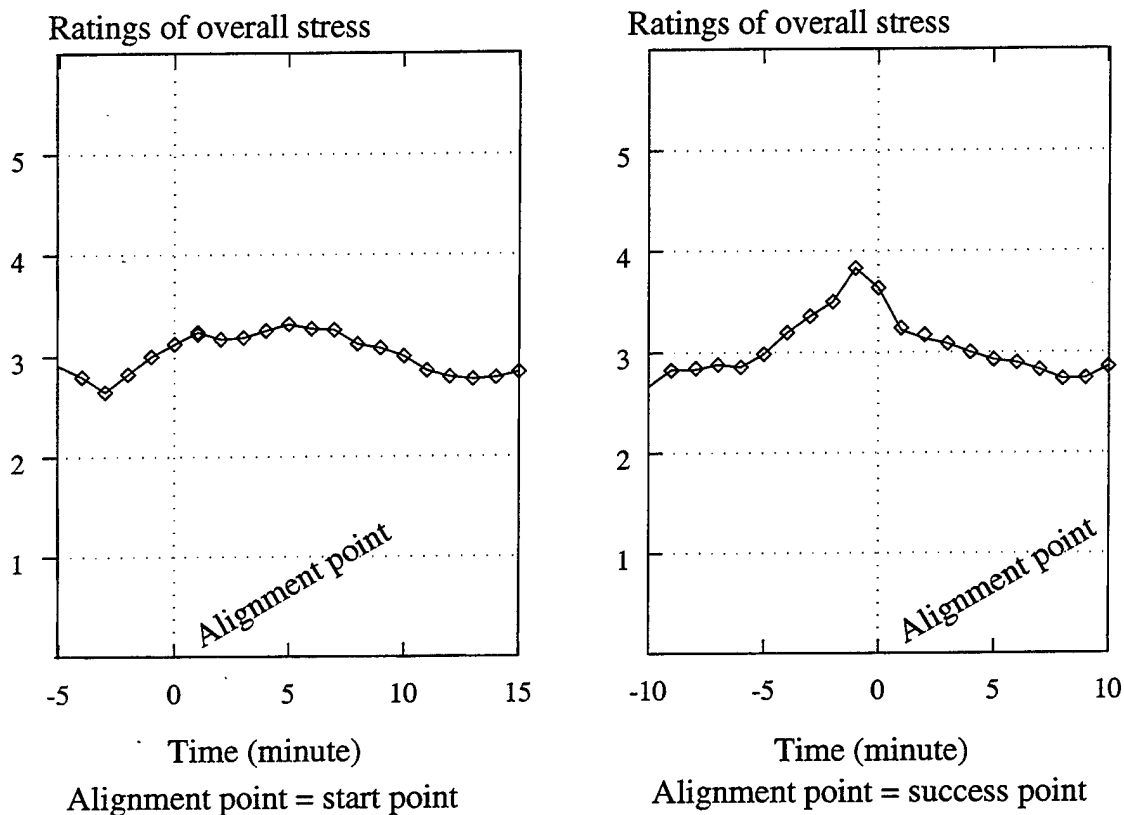


Figure 10.1: Comparison of temporal stress profiles with different alignment points. Two alignment points were compared: the start (left graph) and the success (right graph) point of intubation. Overall stress ratings were aggregated according to the chosen alignment points. Note that the range of the horizontal axis (time) of the left graph is shifted to cover *about* the same time period on the right graph.

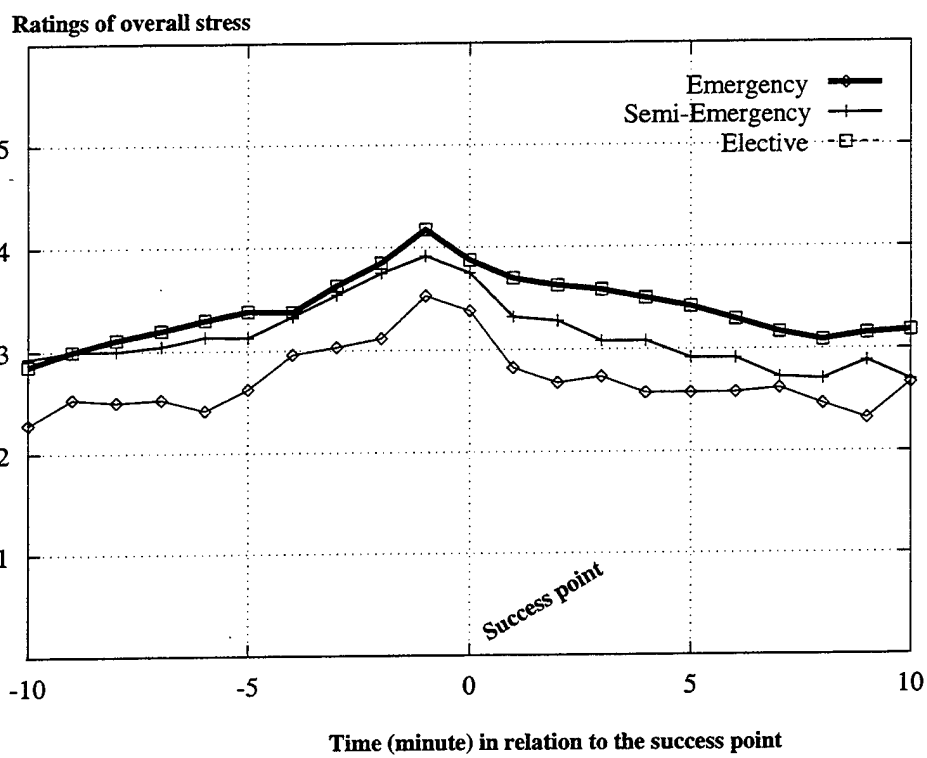


Figure 10.2: Comparison of temporal profiles of stress ratings (the overall stress S7) over the course of intubation with different urgencies.

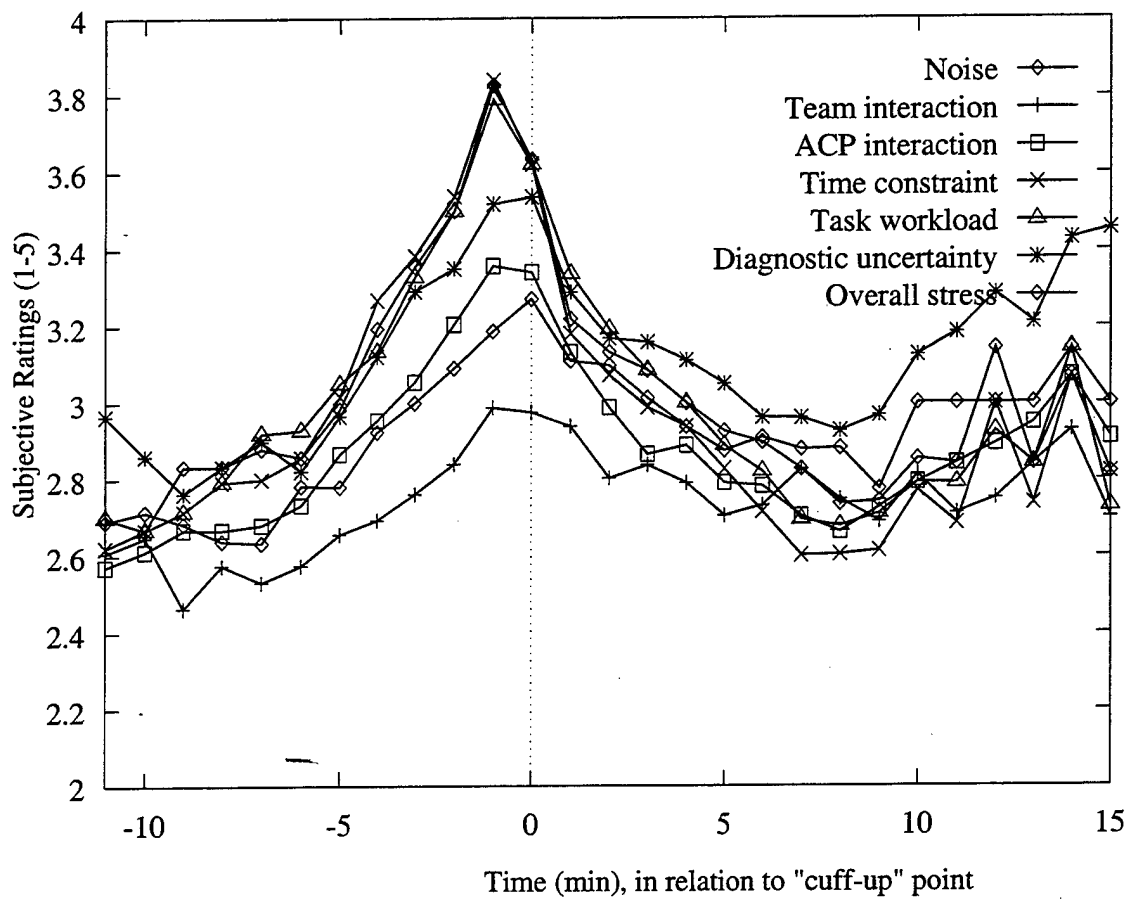


Figure 10.3: Temporal profile of seven measured items of stress.

10.5 Discussions

The temporal profiles (Figures 2 and 3) of the measured stress over the course of the intubation task are probably the most striking results of measurement of perceived stress. The two characteristics in the temporal profiles, the peak point and upward shift of stress ratings with the increase of task urgency, demonstrate the feasibility of measuring dynamic changes of stress by using the videotape review technique described here.

The current study provides answers to several important questions regarding the dynamic measurement of perceived stress. First, from the domain point of view, the intubation in each case progressed differently, but the success point of intubation is a point of relief for the team and in particular for the person who performs the intubation. The raters clearly perceived such relief when reviewing videotaped cases. Although one might expect a rise in stress ratings when tasks become urgent, the nearly parallel increases and decreases in the temporal profiles for the task procedures with different urgencies were surprising. This finding suggests that with the increase of task urgency, there is an elevation of stress *throughout* the task procedure. Without the dynamic measurement of stress, it would be difficult to determine this.

Second, the contrast between the resulting temporal profiles when different alignment points were used shows the importance of methods of aggregating data across cases. When aggregating data through alignment, the resulting temporal profiles are dependent on the choice of alignment point. The context of the task being studied has to be considered for the choice of alignment point.

Third, personal involvement affects how a case is reviewed. The regression weights associated with three of the stressors were found to be significantly different when comparing the ratings from the participant raters with those from the neutral raters (Table 6). When a rater rated his or her own cases (i.e. when he or she participated in the care of the patient), the rater emphasized workload more than did the neutral raters, indicated both by the difference in the regression weights associated and by the rank order changes. One explanation is that participant raters had a better appreciation of the workload involved. Similar explanations can be applied to the stressor 'noise'. It is also interesting to note the decrease in emphasis of the stressor 'diagnostic uncertainty' when participant raters are compared with neutral raters. This difference may be attributed to the fact that the participant raters had personally experienced the case under review and thus felt not as uncertain about the patient's status as did the neutral raters.

Fourth, the strong correlations among the measured items suggest that the raters in the current study perceived stress as a nearly univariate concept, in spite of the intuitive appeal of separately measuring environmental, social, and task-related stressors. This finding corroborates the experience in the subjective mental workload measurement (e.g., Hendy, Hamilton, and Landry, 1993; Nygren, 1991). Among the three types of stressors measured, task-related stressors correlated more strongly with the overall stress than non-task-related stressors. This finding also points out one of the limitations of using the current technique to measure stress. The raters, in the review of videotaped task procedures, were more sensitive to the tasks-related stressors than to stressors related to environmental and social factors such as noise and non-optimal interactions with team members. Further research is needed to determine if video review techniques in measuring stress (such as the one described here) can be used to measure stressors not

related to tasks.

However, it is premature to conclude that subjective stress is a monolithic construct. One of the limitations of the current study is that the seven ratings were obtained in one pass. The cross-influence of the seven ratings could be reduced by having subjects provide one rating for each pass and collecting seven ratings in seven individual passes.

In conclusion, measuring subjective stress dynamically through the use of videotaping show promising results. The study described here captured some of the dynamics of stress during a real-life task procedure. In using the video review technique, personal involvement changes one's ratings on the perceived stress, particularly in task workload and diagnostic uncertainty. Different methods of aggregating data will result in different temporal profiles of stress and the domain context should be considered in choosing appropriate methods. Although multiple variables can be measured simultaneously with the current technique, raters tend to view the perceived stress as a univariate variable. Furthermore, they emphasize task-related factors more than other factors.

Considering the wide availability of video recording technology, the use of videotape reviewing techniques such as the one described here could strengthen our ability to study stress and its impact on performance, especially in situations where continuous measurement of stress ratings is important, for example, during studies of crisis management in aviation and process controls.

10.6 Measurement of Physiologic Responses to Stress

In an attempt to validate the subjective measurement of perceived stress, we instituted a system for monitoring ambulatory vital signs.

Five anesthesia care providers wore monitors (a Holter electrocardiogram monitor and ambulatory blood pressure monitor) while carrying out their duties.

Figure 10.4 shows the electrocardiogram traces of the same anesthesiologist performing intubation in two different circumstances: an elective case and an emergency case. There was a dramatic increase in heart rate during the period. Although it is difficult to separate the influence from physical exertion and stress levels in interpreting the increase, the increase in heart rate was consistent with the results of the measurement of subjective ratings.

Figure ecg-bp shows blood pressure and heart rate readings over the on-call duration (12 hours). Due to the limitation in the analysis software, the readings were averaged for every 15 minutes. The results show the parallel movements of blood pressure and systolic blood pressure. Physical exertion, such as in running errands, appears to have a greater influence on the changes in these two physiological parameters than others, such as stress during airway management. Towards the end of the on-call, the anesthesiologist participated in the resuscitation of a gun-shot-wound patient. There was a dramatic increase in heart rate.

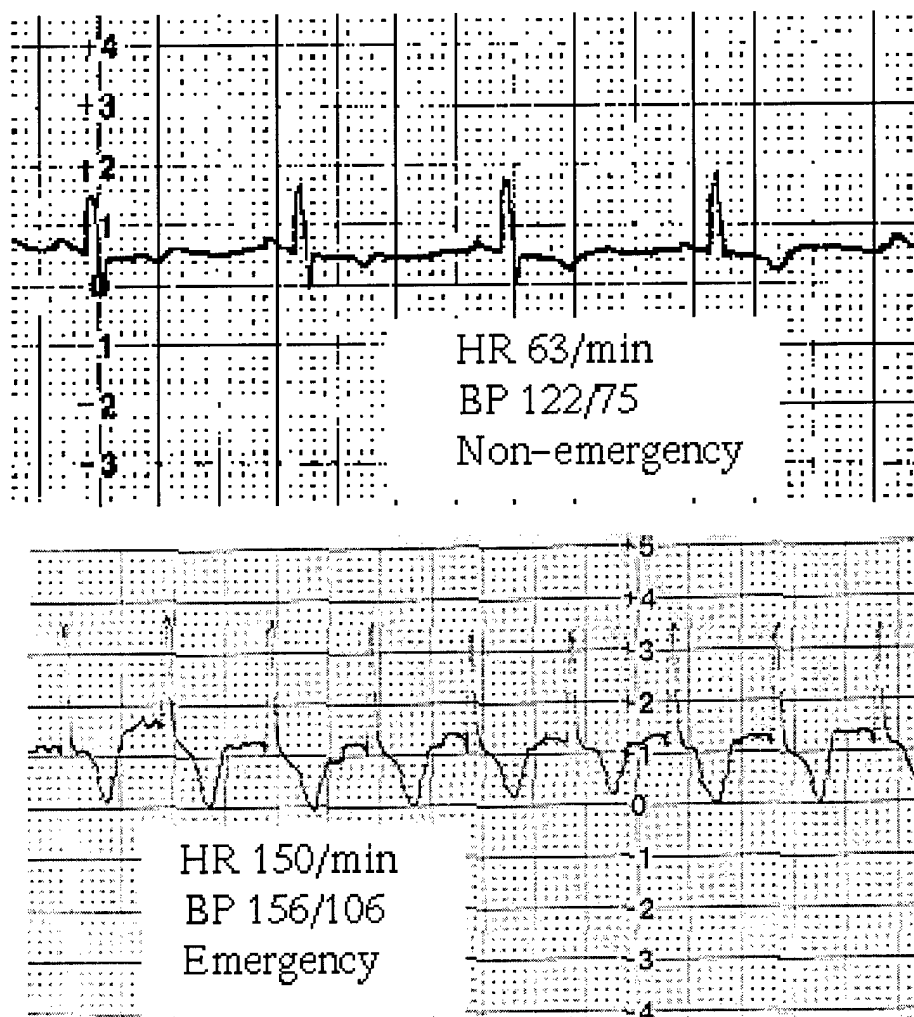


Figure 10.4: Electrocardiograms of an anesthesiologist during elective and emergency intubations. Ambulatory electrocardiogram monitoring of an anesthesiologist during elective tracheal intubation (top panel) showing normal blood pressure and heart rate. The same anesthesiologist two hours later dealing with an emergency intubation has a greater than double heart rate (lower panel) and clinically significant diastolic hypertension.

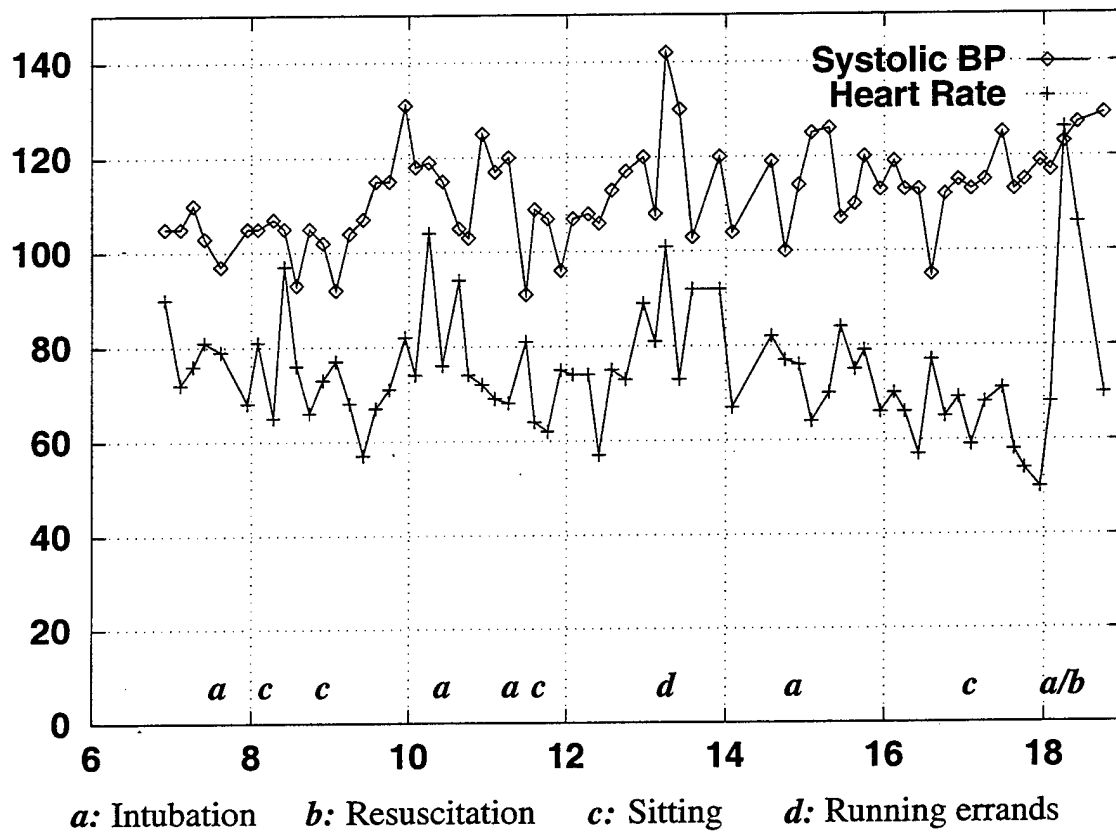


Figure 10.5: Heart rate (HR) and blood pressure (BP) of an anesthesiologist, obtained by ambulatory monitors (Holter). The changes identify increased BP and HR with increased physical exercise (point *d*), but also at point *a/b* during patient resuscitation requiring emergency intubation.

10.6.1 Discussion

The limited cases in the measurement of care providers' physiological parameters provided supporting evidence to the statement that emergency airway management is a stressful episode. However, the lack of specificity to the source of stress make it difficult to separate factors such as physical exertion from the impact of stress.

Chapter 11

Decisionmaking under Stress

11.1 Fixation Errors

This section reports the effort in analysis of fixation errors through the presentation of one case.

11.1.1 The Case

The patient was admitted to the shock trauma center after being struck by a car (traveling at over 90 km/h). He suffered a closed head injury and was unconscious upon arrival at the center. The segment concerned in our analysis (Figure 11.1) started when one of the anesthesia care providers (ACP2; ACP1 was the supervisor) attempted to insert a breathing tube into the patient's trachea (windpipe). In order to do this, the patient was paralyzed with drugs. Once the breathing tube was successfully inserted, oxygen could then be delivered to the patient.

After several apparently difficult maneuvers, ACP2 inserted the tube into the patient's mouth (time 33:58 on Figure 11.1, marked by the circled 'A' at the top of the figure), and started to ventilate the patient through the tube by manually squeezing a ventilator bag. The tube, however, was not inserted into the trachea but instead it was placed in the esophagus. Therefore the patient's lungs were not ventilated and no oxygen was delivered to the patient. Rather, the oxygen was pumped in and out of the patient's stomach. For the five minutes after the tube was inserted (between the circled 'A' and 'E' on Figure 11.1), ACP2 was seeking confirmatory signs about the tube position. At time 38:58 (the circled 'E'), the tube was finally withdrawn and a new tube was inserted. By then, the patient had not been ventilated for over 6 minutes. The pulse oximeter reading and heart rate had dropped to abnormally low levels.

11.1.2 The Evolution of Fixation Errors

The initial doubts of ACP2 about the tube position were offset by the comments made by ACP1 ("feels good"). ACP1 made the comment because he felt the tube passing through the patient's larynx under his fingers while he compressed the patient's larynx (applying

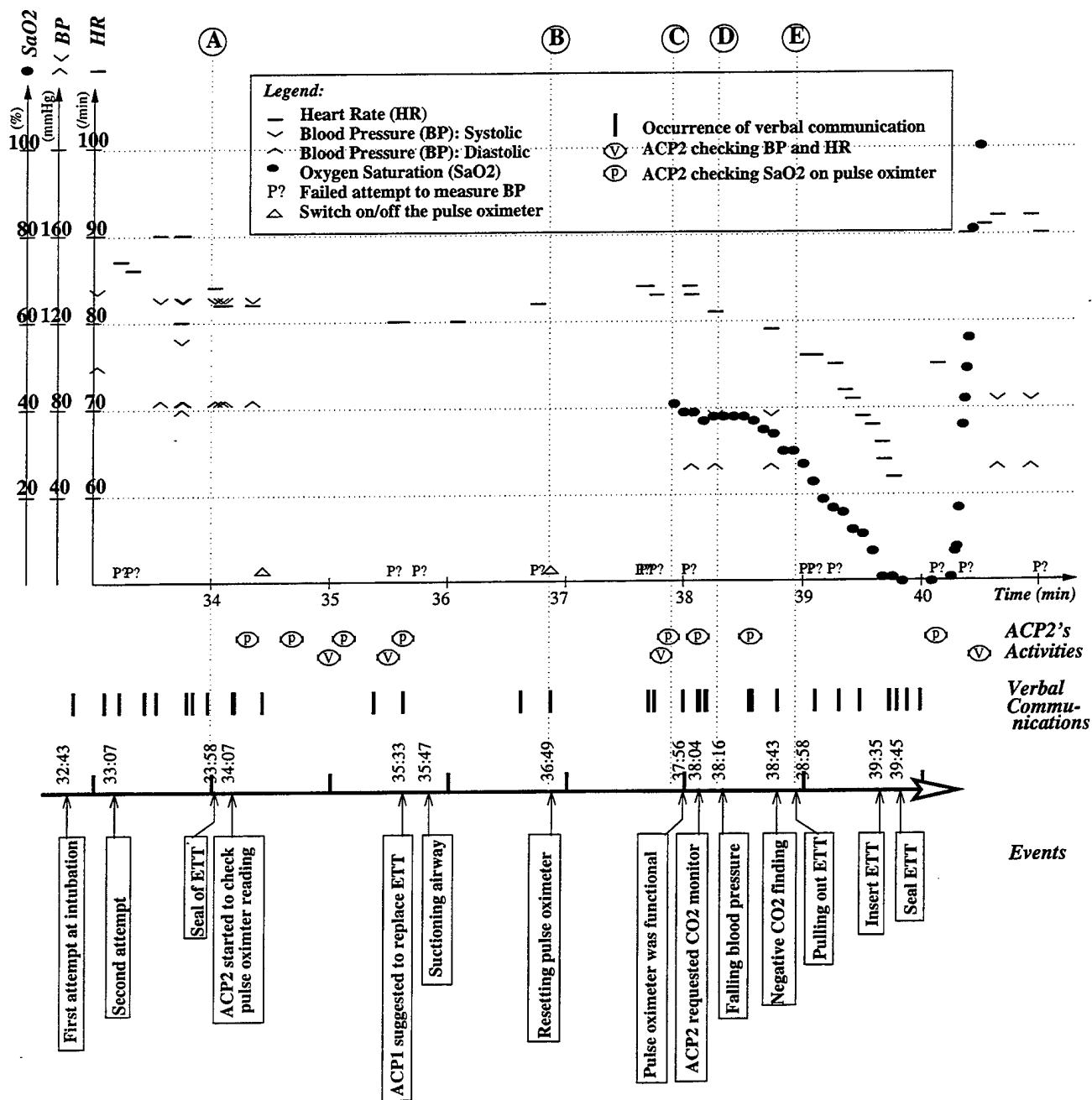


Figure 11.1: Case event overview. The upper portion is the patient's vital signs showing oxygen saturation of blood (S_aO_2 , measured by a pulse oximeter), blood pressure (BP) and heart rate (HR). The symbols used in plotting the patient's vital signs are shown in the rectangle above the plot. The lower portion is the attention pattern of ACP2 and verbal communications of the 6-person team (each bar represents one transaction). The major events are listed along the lower part of the time line.

the so-called "cricoid pressure"). The feel by ACP1 of the tube passing was an *insufficient* test of the correct tube position. To find more confirmatory signs, ACP2 checked the monitors attentively and repeatedly, as shown in Figure 11.1 by the symbols \textcircled{P} and \textcircled{V} . (These monitors were placed behind ACP1 and the act of watching monitors was easily observable during the analysis.) In particular, ACP2 was waiting for a reading from the pulse oximeter (\textcircled{P}), which provides the oxygenation level in the blood (S_aO_2). It is an indirect and also *insufficient* test of the tube position. At high readings (e.g., close to 100%), pulse oximeter readings indicate that the patient does not lack oxygen. However, the pulse oximeter did not function despite repeated attempts to activate it (represented by the triangle symbols in Figure 11.1). During the crucial period after the insertion of the tube (marked by the circled 'A' and 'C'), the team was unable to obtain pulse oximeter readings.

ACP1 and ACP2 (along with the surgeon) were also reading the heart rate (HR) and blood pressure (BP) monitors. The negative (i.e., unstable) readings in the vital signs may also indicate misplacement of the tube, but on the other hand, the positive readings of the two variables were *inadequate* for the confirmation of the correct tube position. At time 36:46, marked by the circled 'B' in Figure 11.1, the surgeon commented that the patient was in a stable condition.

Although ACP2 could not positively establish the tube position after the insertion of the tube, there were indications that the tube might be in a wrong place. The sounds from squeezing the manual ventilation bag were not normal; the tube insertion was difficult and accomplished on the second attempt. ACP1 also suggested to ACP2 (at 35:33) to replace the tube. However, it appears that ACP2 was fixated on getting readings from the patient monitoring devices as the preferred way to confirm the tube position while not considering other direct tests (e.g., looking into the patient's airway by repeat laryngoscopy and listening to the patient's chest for abnormal breathing sounds).

At time 37:56 (marked by the circled 'C' in Figure 11.1), the pulse oximeter finally started to function. It displayed a very low reading (40%), and the pulse rate on it was correlated with other monitors, suggesting it was *not* an artifactual value. This alone was a sign of insufficient oxygenation of the patient and strong evidence of a misplaced tube. However, ACP2 refused to accept this negative reading. To paraphrase the interview given by a case participant (ACP1), people tend to believe the pulse oximeter when it displays "good" numbers (i.e., within the normal range), but discount it when it displays "bad" numbers. Instead of acting on the negative pulse oximeter signal, ACP2 kept on seeking yet more diagnostic information about the tube position by installing a carbon dioxide (CO_2) monitor. The presence of CO_2 in the expiratory gas is a "gold standard" test of a correctly placed tube. The absence of CO_2 *unambiguously* indicates that the tube is incorrectly placed. Soon after the request to set up a CO_2 monitor (time 38:04, between the circled 'C' and 'D' on Figure 11.1), the HR and BP started to show signs of instability. The tone of the pulse oximeter was also falling rapidly (refer to Figure 11.1; note that the pulse oximeter provides audible beep sounds to indicate the oxygen saturation reading.) Still, ACP2 was fixated on his diagnostic strategy. It took 37 seconds to set up the CO_2 monitor and to obtain a reading which confirmed the absence of CO_2 in the ventilating circuit (time 38:43).

11.1.3 Analysis of Fixation Errors

As in the analysis of other types of errors, in real work environments it is often difficult if not impossible to pin-point the causes of fixation errors. The relationships between errors and their causes are often too complicated to allow causal explanations of errors. What we attempt to do in the following is to outline three areas that may have induced the fixation errors. Our focus is on how the inherent nature of the work domain manifests as factors that promote fixation patterns.

Prolonging the Window of Opportunity: Double-Edged Sword?

Certain maneuvers used by practitioners prolong the "window of opportunity" so that time-consuming or potentially time-consuming procedures can be carried out without endangering the system under control. However, in a complex system, the prolonging maneuver itself may become an inducer of fixation errors. One of the possible contributors to the errors in the above case was pre-oxygenation. Pre-oxygenation builds up oxygen reserve in the patient, so that the patient status will remain stable for a longer period of apnea (non-oxygenation). Pre-oxygenation should increase the margin of safety and probably also reduce the time pressure during the delicate procedure of inserting a breathing tube while the patient is paralyzed. Figure 11.2 illustrates a comparison between the patient's oxygen saturation during the insertion of the tube with pre-oxygenation and that without it.

As seen in the case described above and depicted by Figure 11.1, the patient conditions remained stable for a long period of time (more than 5 minutes) after the tube was misplaced and the absence of oxygenation. This may have created a false positive cue for the practitioner and may have increased the tendency to fixate on seeking confirmatory cues rather than on negative cues. (In fact in the domain of anesthesiology, a suggestion has been made to abandon the practice of pre-oxygenation precisely because it delays the manifestation and possibly the identification of improperly placed breathing tubes. (See Howells, 1985.)

Confirmation Bias or Redundancy Check?

The fixation errors in our case amply demonstrate ACP2's tendency to seek cues from various sources to confirm his belief that the tube was in the proper place while at the same time to discount negative cues (*e.g.*, the very low S_aO_2 reading).

However, the confirmation tendency or bias can also be viewed as a strategy to utilize redundancy information channels to deal with the complexity and uncertainty in the patient's physiology and unreliability in monitoring devices. Probably more so than in other medical fields, patient monitoring can be very challenging in the domain of trauma patient resuscitation. Resuscitation may have to proceed even when monitoring devices have not been attached or set up; the patient may be combative. As in the case described above, the pulse oximeter was not functional during the crucial time. There were many occasions where BP could not be obtained (indicated by the '?' marks in Figure 11.1).

In such a working environment, seeking information from redundancy or correlative

channels is an effective way to deal with superfluous negative findings from individual data channels. In many situations, the practitioner is probably seeking the consistency in the data as a whole, rather than picking out inconsistency and then try to account for it. To accomplish this, the practitioner has to rely on his or her pre-conception to establish the primary hypothesis and then seeking for confirmation cues, instead of abandoning the hypothesis upon the first detection of negative cues. Such behavior may be labeled at times as confirmation biases, but it is essentially the working of the strategy of utilizing the redundancy in data.

Fixation Errors: Moving Too Fast or Too Slow?

The practitioners in dynamic environments are facing a delicate balance in terms of changing courses of actions in the ever changing environment, sometimes under extreme stress with little time available for deliberation. In retrospect, they may be judged as moving too fast in adopting new action plans (there are several such examples in our video library that the resuscitation teams should have stayed in a "holding pattern" instead of adopting aggressive plans), or vice versa. For the first type of "error" (moving too fast), the practitioners may have discounted certain cues from the environment and "fixated" on cues and hypothesis improperly. For the second type of "error" (moving too slow), the practitioners may have "fixated" on a course of action and may have been reluctant to change it, despite the evidence that may have overwhelmingly indicated a need for change.

In the case described above, there were many occasions where ACP2 should have considered a change in the course of actions. In particular at the point when pulse oximeter reading was so low, with no direct confirmation that the patient was ventilated, there is little value, in retrospect, to seek further diagnostic cues. In other words, ACP2 was moving too slow. However, in the mind-set of ACP2 at the particular point in time, the *sudden* presence of an unbelievably low pulse oximeter reading may have been interpreted as a false negative. Had the pulse oximeter been functional all along, the trend information from the pulse oximeter would have been available and such low readings (lower than 40% in S_aO_2) may have very well caused ACP2 to accept the reading and changed the course of action promptly.

11.1.4 Discussion

Our analysis highlights the impact of the dynamic and uncertain nature of complex work domains on the strategies used by practitioners. Fixation errors (judged in hindsight) can be costly, but they are partly the results of the interplay between the nature of complexity environments and the strategies used by practitioners in dealing with complexity. From our analysis, two factors can be elicited that may have contributed to the occurrence of fixation errors:

- (i) Lags in feedback information, either as a result of the system dynamics (*i.e.*, long time constants) or of the measuring process (*e.g.*, as in laboratory tests or setting up measuring devices)

- (ii) Unreliable measuring equipment, either because of the inaccessibility of desired measuring target (thus *indirect* measurements have to be used), or because of the high chance of improperly functioning equipment.

Previous studies have demonstrated the impact of lags or delays on the occurrence of fixation errors. For example, Moray and Rotenberg (1989) found, through the measurement of eye movement, that the subjects in their experiment fixated (inappropriately judged by the authors) on waiting for command echos, which was delayed about 15 seconds. In Schwid's (1990) study, the increase of the updating frequency of a periodical measurement device (from every 3 minutes to every 1 minute) decreased the occurrence of fixation errors. Our case study provides further, real-life evidence on the inducing effects of feedback lags on fixation errors.

The analysis of the tendency of fixating on confirmation cues is difficult in naturalistic settings. It is usually the case that the analyst has to do with retrospective accounts and is difficult to appreciate the mind-set or the circumstances facing the practitioners. When non-retrospective data are available, they are often fragmentary (as in the investigation of airline crashes). The video library that we have collected allows us to examine and re-examine the incidents concerned in detail. The availability of system data (*i.e.*, patient physiological measurement) and audio-video recordings make it possible to explore possible causes of fixation errors by examining the context of incidents and actions, without having to rely on retrospective accounts.

In conclusion, fixation errors are a reflection of the complexity of task domains. It induces the behavior of preferring confirmatory information, partly for redundancy checks, and it may create a false sense of system stability at times and divert attention away from the correct diagnosis. Video analysis of real incidents involving fixation errors is particularly valuable in illustrating what *can* happen and in identifying factors inducing fixation errors.

11.2 Stress and Performance

Various relationships between stress and performance have been proposed in previous studies. One of the influential relationships is the inverted U-curve. One of the questions in stress research is: whether performance deteriorates at high stress levels. Since our project could not determine any causal relationship between stress and performance, we attempted to determine if there was any correlational relationships. Thus the question we attempted to answer is: Is performance poorer when stress level is high?

We analyzed 22 videotapes of emergency (12 patients) and elective (11 patients) tracheal intubation. We viewed the videotapes to determine if various procedural checks were carried out before, during and after tracheal intubation and compared the checks made for emergency and elective tracheal intubation. We also documented timing of the achievement of various milestones during the intubation sequence. The data concerning procedural checks is shown earlier in Figure 9.4.

In each category there were fewer activities performed for emergency than elective intubation. The differences in procedural checks performed before elective and emergency intubation were significant ($p < 0.05$). Among the procedures that were omitted in preparation for emergency intubation was placement of monitors of patient

physiological data including O₂ saturation and end-tidal CO₂. The omission of the end-tidal CO₂ (ETCO₂) monitor in one patient resulted in failure to detect an esophageal intubation for several minutes, and in another patient, monitoring of ETCO₂ could have identified an erroneous diagnosis of misplacement of an esophageal obturator device (This device is used in field emergency airway management). So the task shedding and short-cuts that were taken from usual procedural checks resulted in important cascades of adverse consequences for the patient. During tracheal intubation, task shedding also occurred with adverse consequences that potentiated the procedural errors occurring in preparation for emergency intubation. The task most frequently shed during tracheal intubation was for the anesthesia care provider to delegate listening to the chest to another non-anesthesia member of the trauma team. In 9 of 12 emergency tracheal intubations, the anesthesia care provider did not listen to the chest. In one instance, this perpetuated the failure to detect the esophageal intubation. These were, therefore, significant procedural errors that should be able to be corrected with feedback and training for the anesthesia care providers.

In addition to procedural errors, there were three knowledge-based errors. These were not as easy to identify as the procedural errors. All three knowledge-based errors occurred in association with emergency tracheal intubation and concerned dosages of drugs given and route of administration of the drug. Multiple (3-4) stressors were noted in two of these three instances in which knowledge-based errors occurred. In elective intubation, no knowledge-based errors were identified and no more than two (among six that were looked for) stressors were found in any elective tracheal intubation.

We also compared timing of certain landmarks in the intubation sequence. The important data are summarized in Table II.

There were significant differences ($p < 0.05$ unpaired t-test) between elective and emergency tracheal intubation in duration of pre-oxygenation of the patient before induction of anesthesia and direct laryngoscopy (instrumentation necessary to pass the tracheal tube through the vocal cords). Pre-oxygenation is a safety precaution to ensure that O₂ levels remain adequate after anesthesia is induced and during the period of direct laryngoscopy and passage of the tracheal tube through the vocal cords (when no oxygen can be given). The shorter duration of pre-oxygenation occurred in the situation when it may be most advantageous. Equally, it may, in some circumstances, be more appropriate to proceed expeditiously with emergency intubation and forego prolonged preparations. These contingencies need further exploration.

There was a significant difference in the interval between starting to ventilate the patient and looking at the end-tidal CO₂ monitor (detection of ETCO₂ is the 'gold standard' that confirms that the tracheal tube is in the windpipe not the esophagus). This is a clinically important difference. It occurred because the ETCO₂ monitor is immediately behind the anesthesia care providers and also because the sample port for CO₂ is not present in the manual ventilating circuit used immediately before and after emergency tracheal intubation. Only when the patient is connected to the mechanical ventilator is ETCO₂ monitored. There are ergonomic and logistical problems that should be easily rectified. We have recommended implementing changes to prevent recurrence of this delay in placing and observing monitors. In the four years and over 2,000 emergency airway managements, there have been no incidents of undetected esophageal intubation, or other failures to recognize inadequate ventilation in emergencies since these changes in

ETCO₂ monitors were implemented.

11.2.1 Method

To answer the question as to whether performance was inversely correlated with stress levels, we compared the performance in intubation with three levels of task urgency: emergency, semi-emergency, and elective intubation. Stress on ACPs was measured by SR = the percentage of ratings above normal. The reason to choose this measurement was that there were multiple measurements for each case. The chosen measurement provided a way to aggregate measurement over time. The performance in each case was measured by *task omissions* (TOs): the number of unchecked task items in the questionnaire identified by the reviewers, and *decision-making errors* (DM-Err): the number of the checked items in the questionnaire in six areas (inappropriateness in intubation approach, preparation, drugs used, doses, patient monitoring, and decisions).

To further understand whether the stages in intubation made any changes to the relationship, we separately analyzed the phases of pre- (pre) and during (dur) intubation.

11.2.2 Results

A steady increase in SRs was found (Figure 11.3) from EL to SE to EM intubations (significant at $p < 0.01$ comparing EL vs. EM; unpaired t -test was used in all comparisons). During EM intubations, 75% (standard error $\sigma=10\%$) of the SRs were above normal. TOs (pre) were higher in EM than in EL and SE ($p < 0.025$) and DM-Errs in EM were significantly higher than both in EL ($p < 0.01$) and in SE ($p < 0.05$). Pearson r 's (Table 11.1) of SRs with TOs and SRs with DM-Errs in individual cases were, however, small.

11.2.3 Discussion

Our results suggest that in EM cases, on average, ACPs made more inappropriate decisions when compared with EL and SE cases. The increase of TOs in EM cases occurred primarily in the preparation for intubation. One explanation for such changes in performance was that in EM there was more stress imposed on ACPs, as the patients in need of EM intubations were usually in a critical condition. However, when separated into individual cases, TOs and DM-Errs were marginally correlated with the SRs, which only moderately supported the main hypothesis that increased stress induced more errors. Other factors in EM (e.g., deficiencies in training and enforcement of protocols) may have jointly caused the increase in error rates in EM cases.

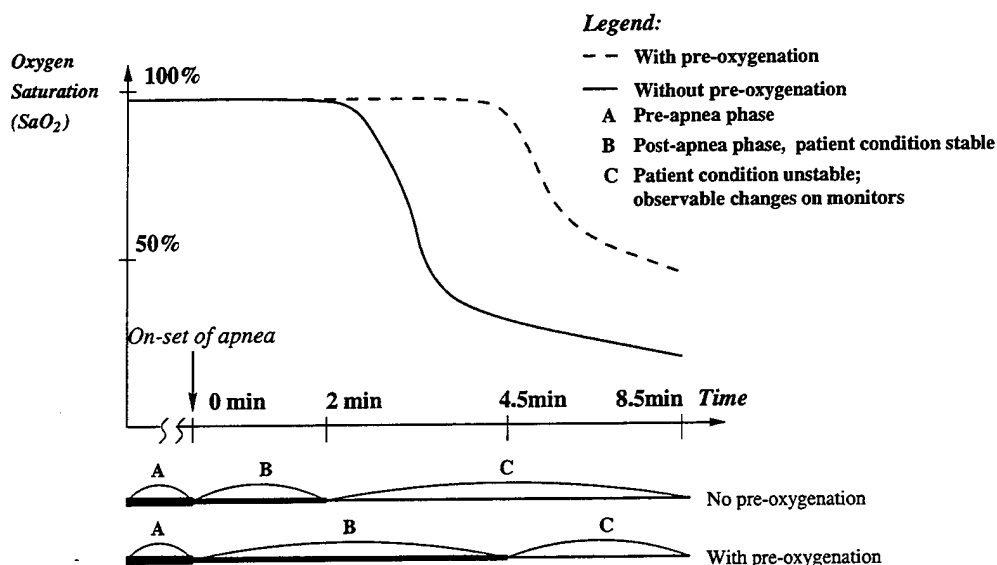


Figure 11.2: Prolonging the window of opportunity through pre-oxygenation. Pre-oxygenation provides a prolonged stable condition, while at the same time delaying the manifestation of underlying problems.

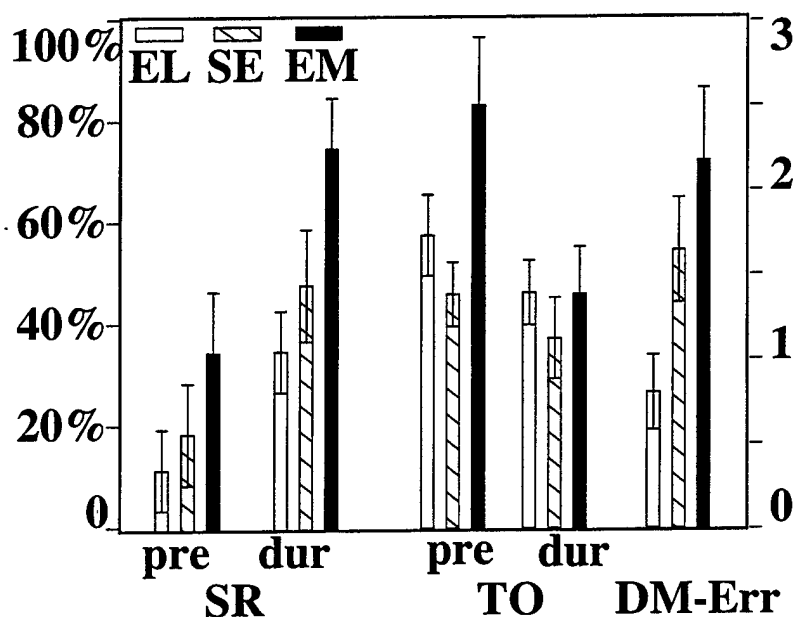


Figure 11.3: Correlational relationship between performance and stress ratings (SRs). TO: Task omissions; DM-Err: Decision-making errors. The phases of intubation are labeled as before (pre) and during (dur) intubation; the type of airway management are elective (EL), semi-emergency (SE), and emergency (EM).

11.3 Video Analysis of Two Emergency Tracheal Intubations

11.3.1 Introduction

A problem with the documentation of what occurred during a critical incident involving anesthesia care is that recall of the event is incomplete or self-serving or the same incident may be perceived differently by several participants (Utting *et al.*, 1979). Allnutt describes reports of such incidents as discussing not what actually happened, but what "must have happened." (Allnutt, 1987) To overcome some of the problems of lack of real-time documentation we videotaped anesthesiology team performance in two resuscitation areas of a trauma center.

The objective of this report is to describe two unusual cases of emergency airway management that illustrate the value of videotaping as a tool for education, quality assurance, human engineering factors and cognitive decision-making research.

11.3.2 Methods and Materials

Videotapes were analyzed using the Observational Coding System of Tools (OCS Tools, Triangle Research Collaborative, Inc., NC), a commercial video analysis software package. Video analysis began when the attending anesthesiologist involved in each of these two cases reviewed the videotape with a nonparticipant subject matter expert (SME), who was an experienced trauma anesthesiologist. The tape of Case 1, the critical portion of which lasted approximately eight-and-a-half minutes, was reviewed four hours after videotaping. The critical portion of the tape of Case 2 lasted approximately six-and-a-half minutes and was reviewed two weeks after videotaping. During the review sessions, the attending anesthesiologists provided a running commentary describing the events, communications, and therapeutic interventions that occurred both on and off the camera's field of view during their respective cases. The nonparticipant SME asked questions as appropriate to elicit more detailed information and to probe the attending anesthesiologists about the context of their observed behavior and the reasoning behind their patient treatment decision-making. These review sessions were audio taped and notes were subsequently entered into an OCS Tools file. Next, the key verbal communications among the trauma team that could be discerned from the audio channel of the videotape were transcribed into another OCS Tools file. These two files were then merged, providing an integrated, time-sequenced transcription of observational notes, commentary, and key verbal communications from the tape. The nonparticipant SME then reviewed the transcriptions and videotapes and recorded in a separate commentary file what was thought to have occurred. The nonparticipant SME and attending anesthesiologist then met again and reviewed the videotape together. Key segments of the videotape were repeatedly reviewed with different hypotheses proposed by the nonparticipant SME to explain what had occurred. The attending anesthesiologist then confirmed or rebuffed the ideas proposed by the nonparticipant SME until, with the help of the video image, the sequence of events that occurred was agreed upon. In Case 1 there was failure to agree on one aspect of patient management (see below). Other aspects of Cases 1 and 2 were agreed upon by consensus among all participants in the analysis.

11.3.3 Results

Case 1

Case 1 illustrates how a procedural error and a knowledge-based error resulted in a risk to the patient. The first of these errors was a failure to monitor ETCO₂ and to adequately check ventilation equipment. The second error was a failure of the supervising attending anesthesiologist to be familiar with an esophageal obturator airway (EOA) and to check the management of a trainee undergoing emergency airway management practice. Despite these events, there was no adverse patient outcome.

The patient had a history of a cardiac arrest in the field. There was confusion in the initial reports about whether the patient had sustained a head injury or whether he was under the influence of drugs or had suffered an epileptiform seizure. Later, during resuscitation, it was learned that the patient was assaulted, had a cardiac arrest, was initially resuscitated at the scene, and was also found in possession of drug paraphernalia. On admission, by ambulance, he was unconscious and being ventilated using a resuscitator bag through an EOA, which resulted in chest movements. With an anesthesiologist in attendance, 2 min were required to transport him to the admitting area. An abbreviated summary is shown in Table 11.2 of the major events that took place during admission and resuscitation of Case 1, as obtained by reviewing the videotape and the video analysis procedure described above.

In the admitting area both the attending anesthesiologist and an emergency medicine physician (EMP), undergoing tracheal intubation training, listened to the patient's chest, but neither made comment on the adequacy of ventilation. The elapsed time in Table 11.2 shows that after two minutes, ventilation was delegated to this EMP. Thiopental and succinylcholine were administered intravenously by the attending anesthesiologist. The EMP had some difficulty visualizing the cords but stated that "the EOA is in the trachea." The attending anesthesiologist who was standing alongside the patient told the EMP to "ventilate again and take it (the EOA) out and change to an ET tube." Cricoid pressure was applied and the EOA removed. The trachea was intubated after the EMP inserted and withdrew a conventional cuffed endotracheal tube (ET) in and out of the mouth three times before passage through the larynx was achieved. The patient's lungs were then manually ventilated using a resuscitator bag and breath sounds were checked by stethoscope. Right-sided endobronchial intubation was detected and the tracheal tube was withdrawn a few cm. The mechanical ventilator was connected but the setting had accidentally been switched from mandatory ventilation to pressure support mode. Because of residual succinylcholine paralysis, the lungs were not ventilated for 48 seconds. This problem was recognized and then corrected, after tracing the fault. The remaining resuscitation and management proceeded uneventfully. The patient awoke on day two and was discharged on day four after admission. Arterial blood gases taken on admission while the lungs were ventilated with the EOA showed PaO₂ 456 mmHg, pH 6.53, PaCO₂ 94 mmHg on 100% O₂. These results showing good oxygenation with hypoventilation indicate that the EOA was correctly positioned in the esophagus. Elevated PaCO₂ and acidosis are reported to occur frequently when the EOA is used after cardiac arrest (Smith *et al.*, 1983; Auerbach & Geehr, 1983).

In Case 1, video analysis enabled identification of the exact communications that took place between the attending anesthesiologist and the EMP as the anesthesiologist could

not recall these before viewing the videotape, nor could he state whether he had monitored ETCO₂. We were able to document the lack of ETCO₂ monitoring early on when the EOA was in place. ETCO₂ monitoring could have confirmed the correct placement of the EOA. We also determined the exact time that the anesthesiologist did monitor ETCO₂. This occurred after EOA extubation, tracheal intubation with an endotracheal tube and connection to the ventilator. We were additionally able to measure the time for detection (50 secs.) and correction of endobronchial intubation (84 secs.) and for detection (42 secs.) and correction (48 secs.) of the lack of mechanical ventilation.

Case 2

In Case 2 a critical airway incident resulted from three independent events: 1) a knowledge-based error about the intramuscular (IM) dose of succinylcholine necessary to produce relaxation; 2) communication failure among the anesthesia care providers; and 3) communication failure between the team leader and the anesthesia team.

On admission, the patient was severely obtunded (Glasgow Coma Scale 9/15) (Teasdale & Jennett, 1974), obese (about 100 Kg), had tightly clenched jaws, an unrecordable blood pressure due to hemorrhage from an abdominal gunshot wound (GSW), and no intravenous (IV) access because he was an IV drug abuser. The major events, determined from the video analysis procedure described above, during admission and resuscitation before proceeding to the operating room (OR) are shown in Table 11.3. The elapsed time in Table 11.3 identifies that during the first minute the patient's lungs were ventilated via face mask, although no quantitative assessment of ventilatory adequacy could be made as SpO₂ and ETCO₂ were not monitored. After one minute the trauma team leader ordered tracheal intubation. Because there was no IV access at this time, the anesthesiologist gave 130 mg succinylcholine IM into the tongue. Within 17 sec the CRNA began blind nasotracheal intubation because he said he "thought [he] could intubate him." However, the attempts caused gagging and then precipitated repeated vomiting. The tracheal tube stimulated vomiting as it was advanced into the esophagus. Moreover the videotape shows that the tube, when in the esophagus, repeatedly diverted the projectile vomitus out of the nasopharynx preventing aspiration. Gagging sounds can be heard on the audio recording preceding the vomiting. The patient became combative. Four mins and 25 sec after admission, IV access was obtained. Succinylcholine 100 mg was given intravenously and cricoid pressure applied. Because of hemorrhagic shock, the IV succinylcholine took two minutes to circulate and produce relaxation adequate for intubation. Orotracheal intubation occurred and resuscitation continued with blood and other fluids. ETCO₂ monitoring began five minutes after intubation, with temperature monitoring occurring shortly thereafter. Because of the patient's obesity and hemorrhagic shock, BP was not obtained until an arterial catheter was placed by cut-down 15 mins after admission. Bleeding from the GSW continued despite external compression and vital signs remained unstable even though two units of blood and 3L of crystalloid fluids were given within 16 mins of admission. The patient died in the operating room 3 hrs after admission from exsanguination, after receiving 52 units of blood, 46L of crystalloid, 20 units of fresh frozen plasma and 10 units of platelets. There was an associated coagulopathy secondary to massive transfusion for vascular injuries to the left iliac artery and iliac vein caused by the GSW.

In Case 2, video analysis enabled exact timing of the sequence of the order for intubation, giving IM succinylcholine, nasotracheal intubation attempts, and IV succinylcholine. The video showed that the patient was still moving after IM succinylcholine before eventual relaxation for oral tracheal intubation after administration of IV succinylcholine. The audio channel documented the patient gagging before vomiting and the failure of the anesthesia care providers to communicate with the team leader or among themselves. The physiological data collection identified that neither ETCO₂ nor SpO₂ were monitored before intubation. In neither Case 1 nor Case 2 did the anesthesia care providers' knowledge that they were being videotaped appear to have influenced their actions.

11.3.4 Discussion

The videotapes document two airway management incidents in real-time. Because of videotaping, this report does not suffer as much from factual uncertainty and absence of recall as many other retrospective reports of airway management. The patients' physiological data were overlaid directly onto the video, as a result there was no need for a second camera to record the patient vital signs. In other studies in which real critical events were captured on videotape in the operating room, analysis was limited because no patient data were available (Goldman *et al.*, 1972).

We analyzed these two videotapes, in which the participants realized something of interest had happened in relation to emergency airway management, to determine whether there were procedural, human factors, ergonomic or training implications that could be learned.

Procedural Issues

The procedural issue identified was inadequate use of ETCO₂ and SpO₂ monitoring. Whether the chest inflation observed during EOA ventilation of Case 1 was due to air entry into the lungs or gastric inflation could have been established by monitoring ETCO₂ or SpO₂ or by direct laryngoscopy by a more experienced laryngoscopist than the EMP. None of these monitors or examinations were used. Lung inflation could be established by listening to the chest, and although this was done, the supervising attending anesthesiologist did not communicate his findings from chest auscultation to the EMP. As a result of this omission of monitoring and communication, the EOA was removed from the esophagus before protection of the airway from aspiration by placement of a cuffed tracheal tube. In Case 2, a normal ETCO₂ waveform and digital displays of ETCO₂ and SpO₂ could have prompted continuation of mask ventilation until IV access was obtained and until succinylcholine could be given by the more predictable IV route. If the vomiting had obstructed the airway, deteriorating values of ETCO₂ and SpO₂ would be valuable in determining when to either use jet ventilation or request the surgical team to perform a cricothyroidotomy (ASA, 1993). However, in reality it is likely that ETCO₂ would have had limited usefulness in Case 2 as the patient was combative, pulmonary blood flow was low and there was potential difficulty in maintaining a mask-fit sufficient to allow adequate monitoring of the low exhaled CO₂. Reduced peripheral blood flow and patient movements would also reduce the likelihood of adequate monitoring of O₂ saturation by pulse oximeter.

Interpersonal Human Factors

The attending anesthesiologist managing Case 1 failed to communicate that air entry was acceptable during EOA ventilation and to convey his uncertainty about the type of airway to the EMP. It was the opinion of the nonparticipant SME that the attending anesthesiologist was willing to let the EMP struggle with the management of the EOA and intubation of the trachea as part of the learning process. The participant anesthesiologist confirmed his reluctance to intervene, on review of the videotape, because he did not think the patient was at risk. The subsequent events including detection and correction of endobronchial intubation and detection of why the mechanical ventilator was not ventilating the lungs all occurred within 1 min of tracheal intubation. For these actions the attending anesthesiologist did intervene and he took over diagnosis and management from the inexperienced EMP, though he disagreed with the nonparticipant SME that he had accidentally changed the ventilator controls to pressure support.

During management of Case 2 there was a failure of communication between the attending anesthesiologist and CRNA, and between the anesthesia care providers and the team leader. The attending anesthesiologist did not clearly communicate the plan of giving IM succinylcholine to the CRNA, nor was there any discussion of the merits of attempts at blind nasotracheal intubation. Both the attending anesthesiologist and the CRNA failed to communicate to the team leader that ventilation was adequate by face mask. There was time and peer-pressure stress induced by the surgical team leaders' order to intubate and immobilize the combative patient so that the surgical aspects of resuscitation could proceed expeditiously. Such social pressures may have been operative in Case 1 when the supervising anesthesiologist failed initially to intervene and in Case 2 when the anesthesia care providers abandoned face mask ventilation. Omission of communication and failure of team coordination have been reported in other time-stress situations, such as may occur during emergency tracheal intubation (Gaba *et al.*, 1987).

Ergonomics

As a result of videotaping these two cases we also established that neither anesthesiologist had recall of the ETCO₂ when tracheal intubation was achieved and the ventilator was connected and functioned. The CO₂ monitor (Nellcor 1000) sampling site was at the Y-piece of the ventilator tubing and in Case 1, PaCO₂ was grossly abnormal. Despite this abnormality, because of the placement of the monitor (which displays both SpO₂ and ETCO₂) on a shelf behind the anesthesiologist in the patient admitting area, the abnormality in ETCO₂ was not recognized and the alarm is scarcely audible in the videotape above the background noise of the resuscitation team. Further ergonomic findings, established on testing after the videotapes were analyzed, were that the Nellcor 1000 takes two mins to warm up, and cannot be tested (by breathing into the circuit) before a patient admission without an alarm sounding continuously after testing is completed. However, if the Nellcor 1000 is switched off after testing, it does not alarm when switched on again, provided it is not retested. Monitors besides the Nellcor 1000 also have the annoying feature of alarming if set up in a ready mode. The Siemens 900C mechanical ventilator is a complex device with multiple switches and dials making it time consuming to trace faulty control settings. It cannot be left in the switched-on ready state

delivering a tidal volume without a continuous auditory alarm unless it is attached to an anesthesia circuit reservoir bag that acts as a model lung. Both of these ergonomic factors together with the complexity of the Siemens 900C control panel, the necessity to disable the apnea alarm and the position of the Nellcor 1000 behind and remote from the anesthesiologist, made implementation of ventilation and monitoring of ETCO₂ and SpO₂ during initial resuscitation more difficult. The Nellcor 1000 has now been relocated in the patient admitting area to an eye-level position above the Siemens 900C and both the Nellcor 1000 and the Siemens 900C can be tested to ensure correct operation and then switched off to prevent continuous auditory alarms. These changes have made SpO₂ monitoring more readily available, but have not increased the use of ETCO₂ monitoring during resuscitator bag ventilation and immediately after intubation because this requires an additional Y-piece connector. We have recommended placement of such an ETCO₂ monitoring connector in the resuscitator bag circuit, but have not yet assessed whether it has changed the frequency and timeliness of ETCO₂ monitoring.

Training

From the analysis of the management of Case 1 it is clear the anesthesia care providers and trainees need training in alternate airway management devices such as EOA (Smith *et al.*, 1983), EGTA (Auerbach & Geehr, 1983) the Combitube and laryngeal mask (Brain, 1983). Unfortunately, there are no training devices that entirely substitute for real emergency tracheal intubation so that it is common practice to train people using the "hands on" approach, although training devices can be used to provide the rudimentary training about the EOA that was missing in Case 1.

Management of the patient in Case 2 identified a knowledge based error about the dose of intralingual succinylcholine. Although succinylcholine by this route has over twice as rapid an onset (in normal children), than when given IM (Mazze & Dunbar, 1968), the dose given in Case 2 of 1.3 mg/kg was much lower than the 3-4 mg/kg recommended for IM use (Liu *et al.*, 1981). If intralingual succinylcholine is given, even to normovolemic patients, it is clear that more than 17 seconds must elapse (Table 11.2) before tracheal intubation is attempted. One of the lessons learned from this videotape was that intralingual succinylcholine was not efficacious in hemorrhagic shock. A second lesson was that the decision to intubate was correct, but the timing of implementation was erroneous. Mask ventilation could have continued until IV access was obtained.

Both Case 1 and Case 2 suggest that the anesthesia care providers would have benefitted from use of SpO₂ and ETCO₂ monitoring to confirm the adequacy of oxygenation and ventilation before deciding to remove the EOA (Case 1) or abandon mask ventilation (Case 2). These monitors were available. As noted in the analysis of pilot errors in the cockpit, problems encountered are often due to the crews' inability to use resources which are readily available (Caro, 1988; Howard *et al.*, 1992).

It is of interest that neither of these two scenarios that were videotaped during emergency tracheal intubation appear in the Anesthesia Crisis Resource Management (ACRM) training in a comprehensive anesthesia simulation environment (Howard *et al.*, 1992; Gaba & DeAnda, 1988) nor in the Gainesville Anesthesia Simulations (Good & Gravenstein, 1989) nor in a Flight Simulator for General Anesthesia Training (Schwid & O'Donnell, 1990). The ACRM course, although including IV failure, does not identify

inability to start an IV as a critical incident (Howard *et al.*, 1992). These and other unusual and interesting occurrences recorded from real clinical care could usefully be incorporated into simulator-based anesthesia training.

Videotaping as a Tool for Research

There are both strengths and weaknesses in analysis of videotape of real patient management for education, quality assurance, human factors and ergonomic research. The major advantages are that the participant anesthesia care providers are not dependent as much on memory, as the video image and audio recording recreate the event, including comments by the team members and alarms that might not have been heard or noted at the time. In our experience with these two cases, discussions among the participant and nonparticipant SMEs provided additional information that would not necessarily have been revealed without the video image and audio recording. We think that it would have been more difficult to target points where performance could have been changed without the video-image and audio-channel. The participant anesthesia care providers found video analysis useful and they noted that it allowed them to reflect on their performance in greater detail than is possible without it. They found it revealing to discuss the video with the nonparticipant SME, e.g. in Case 1, the attending anesthesiologist did not realize, other than emergency replacement of the EOA, that the management was not ideal patient care. It was only on reviewing the videotapes that it became apparent how improved communication, checking of the EMP's clinical examinations and diagnosis and use of ETCO₂ monitoring would have avoided the need to remove the EOA without first intubating the trachea.

The video acquisition system acquired physiological data in the same manner as an automated anesthesia record by serial interface with patient monitoring systems (Moon, 1987). The added advantage of video acquisition is the ability to see when events occurred and what was done. We were able to see when the anesthesia care providers interacted with the anesthesia machine (e.g., change vaporizer settings) the ventilator (e.g. check or change control dials), the patient monitoring systems (e.g. initiate or calibrate) or the patient (e.g. suction trachea, inject drugs or give IV fluids). We could also more easily check physiological data for artifacts (e.g. seeing transducer balancing or flushing, adjustment of pulse oximeter probe) by viewing a video than observing the printout of an automated anesthesia record. The audio channel provided information about team interaction, verbalization in relation to tasks, what information the anesthesia care providers were focussing on not just information about the patient status. There was also the ability with video acquisition to get information after-the-fact, about events or interventions that were not thought of or attended to at the time.

The weakness of video analysis is that it is tedious and time consuming. It is difficult to accurately estimate how much time was required to analyze each of these videotapes because much work was spent in development of the analysis system and database necessary to facilitate video analysis of these cases and others. About ten hours were spent in discussion, viewing and transcription of the eight-and-a-half minutes of Case 1. Case 2 took less time to analyze because the issues of interest that were unusual occurred within six-and-a-half minutes culminating with the intubation of the trachea. The critical event of no airway access and no IV access combined with patient vomiting was

more obvious than the events in Case 1. Discussion of Case 2 was more straight forward in reaching a consensus and required only about four hours for analysis.

Other weaknesses of video analysis are that even with a two-microphone system it is difficult to pick up all the utterances and the audio record could be improved. However, we believe it would be more obtrusive to equip the anesthesia care providers with microphones. The video image does not include the entire field of view and cannot identify events occurring off the screen, though the audio channel can be helpful. In analyzing a video image with the physiological data overlaid there is a tendency to think that the participants were aware of these data, when in reality this is unlikely because of selective attention to other aspects of anesthesia care. Because analysis occurs after-the-fact, the anesthesia care providers have time to rationalize the decisions made as they are aware of the outcome. Thinking aloud, and interviews conducted in the middle of case management have been used in simulated anesthesia cases to overcome this problem (Howard *et al.*, 1992; Gaba & DeAnda, 1988). Nonetheless, video analysis is better than an automated anesthesia record at determining how decisions occurred because the video and audio recording of all the decision-makers can be repeatedly reviewed. As a result, it is more difficult to make convincing rationalizations for alternate decisions when reviewing a videotape than the automated anesthesia record.

We believe the real anesthesia environment has many advantages for the study of critical incidents over simulation, including more variability, uncertainty, management options, stress, complexity, and potentially adverse consequences than simulation. Videotaping of the real environment enables management of critical incidents and current anesthesia practices to be repeatedly and intimately analyzed. We believe that simulation should be used to practice ideal management of critical incidents. Video analysis of such real events will be important in development of the database necessary for simulation and to improve anesthetic practice and equipment in the future (Mackenzie, 1995).

Video analysis of these two emergency intubations suggests measures that may improve anesthesia care providers management of similar cases including:

- 1) Skills Training (Utting *et al.*, 1979; Howard *et al.*, 1992; Lauber, 1977) - e.g. correct IM dose of succinylcholine; withdrawal of tracheal tube with gagging; conventional tracheal tube insertion before removal of EOA; monitoring of ETCO₂ and SpO₂.
- 2) Crew Training (Howard *et al.*, 1992; Backer & Orasanu, 1992) - e.g. improve communication among trauma team.
- 3) Stress Reduction (Backer & Orasanu, 1992; Spettel & Liebert, 1986) - e.g. education, rehearsal, and application.

These three measures should be discussed in an educational setting, ideally practiced in a simulated environment then implemented in real-life. We believe it is by systematic study of such real critical incidents that the mechanisms involved in their genesis will be understood and from these analyses preventive measures or particular approaches to training may be devised.

11.4 Prolonged Esophageal Intubation

Even experienced anesthesia care providers may occasionally intubate the esophagus. Many techniques and devices have been described to detect esophageal intubation (Birmingham *et al.*, 1986; Linko *et al.*, 1983; Pollard & Junius, 1980; Wee, 1988; Kerr, 1987; Howells & Riethmuller, 1980; León *et al.*, 1994; Murray & Modell, 1983; Clyburn & Rosen, 1994). We report here the analysis of videotaped events during an esophageal intubation that remained uncorrected for six minutes following emergency airway management in a trauma patient. Formal analysis of the events permitted uncovering of the root causes of failure to expeditiously correct the tracheal tube misplacement.

11.4.1 Methods and Materials

Videotape Review

The videotaped patient management was reviewed separately with the two anesthesia care providers (ACP1 = Supervisor, ACP2 = Laryngoscopist). Each provided a commentary that was audio-recorded. Audible communications on the videotape were transcribed using OCS Tools. Two non-participant subject matter experts (SMEs) reviewed the videotape and made commentaries which were also audio-recorded. In addition, the SMEs completed an intubation analysis form developed to examine tasks performed in the intubation sequence (Hunter *et al.*, 1994). ACP1 then repeatedly reviewed parts of the videotape with one of the SMEs while audio-recording a discussion of some of the factors that have been reported in the literature as signs of correct placement of the endotracheal tube (ET tube) in the trachea. The object of these reviews was to seek root-causes of the failure to correct the esophageal intubation expeditiously and to identify the specificity and sensitivity of the tests that were used at the time to detect whether the ET tube was correctly placed. The video analyzers also determined the frequency and duration of ACP1 and ACP2 viewing the vital signs and pulse oximeter/end-tidal CO₂ monitor to ascertain what physiological signals the ACPs were searching for in the 6 min after esophageal intubation. The process required observation of when the ACPs looked at the monitors and was simplified by the positioning of the monitor displays. When the ACPs were in the intubating position at the patient's head, the vital signs monitor was positioned about three feet above and behind the ACP's right shoulder, while the pulse oximeter/ETCO₂ monitor was placed about two feet behind their left shoulder at about eye level.

Twenty-two months after the event and about 18 months after most recently viewing the videotape, ACP1 was provided with the written anesthesia record (date, time and patient's identifiers removed) and requested to complete an Australian Incident Monitoring Study (AIMS) report form after reading the AIMS paper describing the forms' use and purpose (Webb *et al.*, 1993). ACP1 also completed a questionnaire devised by us for our study that we called the post-video recall questionnaire. The questionnaire asked for specific information about duration of pre-oxygenation, monitors in use, number of intubation attempts, time to successful intubation, and values of patient vital signs together with identification of tasks completed in association with induction of anesthesia and tracheal intubation.

Case Report

The patient was a pedestrian struck at 60 mph. He sustained a closed head injury (Glasgow coma scale 6/15), a right hemo-pneumothorax and a left tibia/fibula fracture and pelvic fracture. He was unconscious, alcohol intoxicated and required cardiopulmonary resuscitation at the scene. Videotaping began on admission, when vital signs were heart rate (HR) 80/min, BP 110/80, temperature (Temp) 34.8C. He was pre-oxygenated with a tight fitting anesthesia face mask for 8 min 50 sec before the first laryngoscopy during which time a neurological exam was completed. Seven min 50 sec after admission ACP1 gave 100 mg lidocaine, then induced anesthesia with thiopental 275 mg and administered 125 mg succinylcholine 8 min 14 sec after admission. Two separate attempts were made to intubate the trachea. Ten min after admission esophageal intubation occurred and remained uncorrected for 6 min. The esophagus was extubated and the third laryngoscopy resulting in tracheal intubation occurred 16 min 7 sec after patient admission. The patient left the patient admitting area for a computer tomography scan 12 min after the esophageal intubation was rectified and videotaping ended.

Events and Communications during Anesthetic Induction and Intubation

Before induction of anesthesia, electrocardiogram (ECG) and BP, but not pulse oximeter hemoglobin O2 saturation (SpO2) and ETCO2 were monitored and displayed (Figure 11.1). ACP1 applied cricoid pressure immediately after injection of succinylcholine. After the first direct laryngoscopy, ACP2 ventilated with a resuscitator bag, heard guttural sounds and removed the ET tube. On the second laryngoscopy help was requested in manipulating the position of the larynx (ACP2 said, "This way, this way!"). ACP1 said, "Feels good," as the ET tube passed beneath his fingers applying cricoid pressure.

The ET tube cuff was sealed (Figure 11.1) and the resuscitator bag attached. A fourth year medical student (MS IV), not undergoing training by the ACPs, listened to the chest during resuscitator bag compression and nodded yes in response to ACP2's question, "Did you hear sounds all right?" The MS IV then listened over the epigastrium and after the ACPs had just completed a conversation about removing cricoid pressure stated, "It's also going in here too." (referring to his hearing of air entry into the stomach). This statement was not repeated and was apparently not heard by the ACPs or the nursing or surgical staff standing nearby. There was a lot of concurrent noise and laughter from the next patient admitting area of non-task related conversations among several people. This lasted from just before seal of the ET tube (see Figure 11.1) for the next 70 sec.

The patient's lungs were manually ventilated with a resuscitator bag for 5 min 10 sec after esophageal intubation except for three interruptions totaling 50 sec during which the ET tube was suctioned and lavaged (see Figure 11.1). It was 6 min, 2 sec after anesthetic induction before a pulse oximeter signal was obtained. During this time, neither ACP1 or ACP2 auscultated the chest or epigastrium. The frequency of looking at the vital signs (BP, ECG and Temp) monitor, pulse oximeter and ETCO2 monitor are shown in Figure 11.1. One min 47 sec after esophageal intubation, ACP1 said, "Should you pull the tube out?" ACP2 responded, "No." For the next minute there was no conversation, ACP2 suctioned the ET tube and a surgeon stated, "He's got a good pulse," to which ACP2

responded, "We're in there." Four min after the esophageal intubation, ACP2 said to ACP1, "Listen to the chest." Neither ACP carried a stethoscope so ACP1 borrowed one from one of the nursing staff just as the pulse oximeter (which was attached but not providing a signal) started to function. A nurse read the signal out loud as follows: "correlates well with pulse and says 39 to 40."

The ACP2 then requested the CO₂ analyzer and added it to the resuscitator bag circuit. Thirty-seven sec later ACP1 stated, "No CO₂ – never even budges." A further 24 sec passed by during which the ACPs were not communicating and not performing any appropriate actions to rectify the situation. During this period they seemed unable to make any decision about what to do next. ACP1 then asked, "Do you want a new tube?" ACP2 responded, "Let me get this thing out of here," as the ET tube was removed without application of cricoid pressure. ACP2 attempted the third direct laryngoscopy without re-oxygenation of the patient. He was unassisted, despite five people standing right next to him for a further 34 sec until one of the five said, "Get cricoid pressure on!" ACP2 asked whether the emergency tracheostomy kit was ready 3 sec before passing the ET tube and exclaiming, "That's it!...That's in!"

Hyperventilation with the resuscitator bag began and ACP2 said, "That's better." ACP1, viewing the CO₂ analyzer after 22 sec of hyperventilation, said "End-tidal sixty-five," then "Put him on the blower [ventilator]." Exactly 7 min after the uncorrected esophageal intubation began, ACP2 says, "It's coming up" (referring to the pulse oximeter reading) and 2 sec later, "There we go, 99." Vital signs at the nadir of deoxygenation were HR 62, BP 76/54 and SpO₂ <5%. Within 39 sec of tracheal intubation, SpO₂ was reading 99% and after 2 min 10 sec, HR was 90/min and BP 158/105.

Recall of Events

On the completed AIMS forms factors contributing to the incident were identified as a communication problem, error of judgement, haste and ETCO₂ not used. Factors minimizing the incident were listed as monitor detection and supervision. Suggested corrective strategies were improved supervision, quality assurance activity and specific protocol development. ACP1 was unable to recall the time of day or month of the incident or the ASA status or outcome of the patient.

The completed post-video recall questionnaire identified 3 min as the duration of preoxygenation (actual time of 7 min 53 sec) about 4 min as the time between induction of anesthesia to intubation (actual time of 7 min 47 sec), about 4 min between cessation of pre-oxygenation to completion of taping of the tube in position (actual time of 9 min 39 sec) and more than 2 min as the first time that ACP1 looked at the CO₂ monitor after intubation (agrees with videotape showing ACP1 did not look at the CO₂ monitor before leaving the field of view 2 min after eventual tracheal intubation). ACP1 correctly identified the monitors in use before the first direct laryngoscopy, the occurrence of in-line neck stabilization, suction, cricoid pressure and the failure to re-oxygenate between the second and third intubation attempts. ACP1 was unable to recall the patient vital signs before or after intubation or recall whether oxygen desaturation to <95% occurred during any of the intubation attempts. Three separate direct laryngoscopies were performed (Figure 11.1) and ACP1 recalled only two.

Patient Outcome

The first blood gas was drawn one hour after correction of the esophageal intubation and showed PaO₂ 438 mmHg, pH 7.42, PaCO₂ 31 mmHg, SpO₂ 99%, base deficit -2, HCO₃-20.8 on FiO₂ 0.8 and tidal volume 800 ml, rate 11/min and positive end expiratory pressure of 5 cm H₂O. The computed tomography scan showed intraventricular hemorrhage and cerebral contusions. Intracranial pressure measured by bolt was 10-15 mmHg. Glucose was 229 mg/dl and blood alcohol level was 228 mg/dl. The patient underwent reduction of the left tibia and fibula fracture and intramedullary rod placement. Intraoperatively he became hypotensive due to an anaphylactoid reaction to fresh frozen plasma. He was discharged to a rehabilitation hospital 15 days after admission with significant cognitive impairment. The cardiopulmonary resuscitation at the scene, alcohol levels at the time of head injury, the hyperglycemia and intraoperative hypotensive episode make it difficult to determine the effects of the esophageal intubation on the patient's final outcome.

11.4.2 Discussion

Every experienced anesthesia care provider has at one time in their career accidentally intubated the esophagus. What makes this report of interest is that recognition was prolonged and the event was well documented. This report describes a failure of adequate clinical examination, patient monitoring and team communications. However, the complex analysis possible with this videotaped event identifies many additional interacting factors beyond the control of ACP1 and ACP2 that also contributed to prolongation of uncorrected esophageal intubation. These contributing issues are referred to as system factors because they are caused by the organization, structure or administration of the work environment (Bogner, 1994).

Modalities to Detect Esophageal Intubation

ETCO₂ monitoring At the time of videotaping, it was not possible for the ACPs to monitor ETCO₂ while using the resuscitator bag ventilating circuit unless they removed the CO₂ analyzer connection and sampling port from the mechanical ventilator breathing circuit. When ACP2 requested that this be done, a pulse oximeter signal of 39-40%, correlated with heart rate, indicated that there was a problem with oxygenation, and thus his request for the CO₂ analyzer was superfluous.

The system factor making it difficult to monitor ETCO₂ has been rectified in all 10 patient admitting areas where resuscitator bags are used as the initial means of ventilation before and immediately after tracheal intubation. All resuscitator bags now have the CO₂ analysis connection and sampling port included in their circuitry. We have followed institution of this recommendation for four months and have achieved 92% compliance in the 10 locations randomly checked twice a month.

Auscultation ACP1 did not carry a stethoscope and in the videotape review stated that he rarely does. ACP2 had a stethoscope but lent it to a nurse just after the patient was

admitted. When ACP1 first used a stethoscope (4 min after esophageal intubation) he did not listen to the upper abdomen and seemed uncertain about whether he could hear breath sounds because at the same time a chest tube was being placed to relieve the right hemo-pneumothorax and the chest was draped. It is possible that the pneumothorax could have caused transmitted breath sounds from the epigastrium to resonate loudly in the chest so adding to the diagnostic confusion about lung air entry. Auscultating the epigastrium in comparison to the chest may have avoided this confusion.

Observation of monitors A cause for the failure to detect the esophageal intubation was the heavy dependence both ACPs placed on the monitors and the failure of the pulse oximeter to provide a signal. The advent of pulse oximetry and continuous ETCO₂ monitoring makes clinical examination of the chest a confirmation of what the monitors display, so that identification of tracheal intubation is possible without auscultation of the chest (León *et al.*, 1994; Caplan *et al.*, 1990). This excess dependence on pulse oximetry rather than clinical examination by the ACPs or use of ETCO₂ analysis is a training problem and appears to have been the major factor in delayed detection of esophageal intubation.

System factors

Communication failure Had the comment by the MS IV, "and it's going in here too," made after auscultation of the upper abdomen been heard or had the MS IV understood the significance of what he heard and repeated his findings, then the remaining chain of events might never have occurred. Loud conversation and laughter from an adjoining patient admitting area and a communication between ACP1 and ACP2 about removal of cricoid pressure may have prevented the ACPs from hearing the comment. However, a surgeon and the two ACPs were not more than 2.5 feet away and two other factors may have shifted their attention to other matters. The first was the comment, "Feels good," made by ACP1 as the tube passed beneath his fingers applying cricoid pressure and the second was that the MS IV nodded his head yes to hearing breath sounds after listening to the left then right sides of the chest. These positive findings appeared to be adequate confirmation that the tube was correctly placed, so narrowing attention (Weltman *et al.*, 1971) of the team away from the MS IV's subsequent critical comment identifying air entry into the epigastrium. It is apparent from this case and others (Mackenzie *et al.*, 1994; Gaba *et al.*, 1994) that clear communication among the team is required during trauma patient resuscitation.

Ad hoc trauma team From the patient records, it was very difficult to find the training status of MS IV who was doing a surgical subinternship and administratively functioning as the surgical resident admitting the patient. Difficulty in knowing both the role and the level of training of trauma team personnel is complicated by several systems factors including, the ad hoc weekly and monthly rotations of team members in-training (MS IV, emergency medicine, surgical and anesthesia residents, certified registered nurse anesthetists and nursing students, emergency medical technicians and trauma technicians); the random assembly of team members dependent on how many other patients, in addition to the one just admitted, require simultaneous management; the call

schedules of anesthesia and surgical personnel rotate independently so the same team does not work together all the time; the lack of identification of the roles or status among the trauma team members. Team coordination and communication could be improved by team training, limiting trainee rotations, coordinating call schedules of anesthesia and surgical team members and establishment of a visual symbol for identification and status among all team members participating in patient resuscitation (e.g. color coded hats or gowns with name and status tag). Had the person auscultating the chest been identified as a MS IV, the ACPs might have been less willing to accept his findings on examination of the chest.

Fixation Error

DeKeyser and Woods (DeKeyser *et al.*, 1990) have described three main types of fixation errors including the failure to revise a diagnosis or plan despite evidence to the contrary; the persistent belief that no problem is occurring despite plentiful evidence that it is and the persistent failure to commit to the definitive treatment of a major problem. The analysis of underlying psychological factors of fixation errors has been previously reported (Xiao *et al.*, 1995). Several authors describe the possible occurrence of fixation error in anesthesiology (Gaba *et al.*, 1995; Weinger & Englund, 1990) or in simulated anesthesia care (Schwid & O'Donnell, 1992). This Case Report confirms that fixation error does occur in real-life clinical anesthesiology. The response of ACP2 to the question "Should you pull the tube out?" 2 min after esophageal intubation, ACP2's statement "We're in there," the frequent observation of the pulse oximeter and the delay in responding to the low BP and O2 saturation and the absence of ETCO2 suggests that the ACPs exhibited all three types of fixation error described by DeKeyser and Woods (DeKeyser *et al.*, 1990).

The ACPs in this case gave credence to the weak indicators of ET tube placement in the trachea ("Feels good," nods yes on listening to chest, "pulse feels good," i.e. stable vital signs, "We're in there") rather than the more reliable indicators of the low pulse oximeter readings and hypotension (everything's OK fixation). In reviewing this case, ACP1 stated that "people tend to believe the pulse oximeter when it displays normal values but discount it when it gives abnormal values." ACP2 sought yet more diagnostic information by inserting a CO2 analyzer into the ventilating circuit instead of corroborating SpO2 readings with clinical examination and vital signs data. With a falling BP, a slowing heart rate and the statement "No CO2" they still seemed unable for 30 sec to definitively treat the problem by repeating the direct laryngoscopy, removing the esophageally placed ET tube, and giving O2 to the patient (a persistent failure to commit to the definitive treatment fixation, i.e. the tube is in the correct place and it can't be in the esophagus).

Error Recovery

Nearly eight minutes of preoxygenation delayed detection of esophageal intubation because the patient remained adequately oxygenated. This effect of preoxygenation has been previously described (Howells, 1983) and analyzed (Xiao *et al.*, 1995). Good error recovery depends on the activation of intervention patterns in response to certain cues before control is lost. The ACPs in this case showed inappropriate error recovery as they did not respond expeditiously to the cues of decreasing HR, low BP and SpO2 values

indicating that there was a possible airway problem. The team failed to apply cricoid pressure when the esophageal tube was removed. ACP2 also failed to re-oxygenate the patient before the third direct laryngoscopy when it was clear the patient was hypoxemic. These failures to carry out standard operating procedures or establish a "holding pattern" by stabilizing the patient's oxygenation (e.g., by face mask ventilation and oxygenation) and reassess the situation are additional examples of delayed error recovery.

Recall and Reporting

Most retrospective reports of critical incidents are dependent on recall of the events by the participants at a later date, often months or years after the incident. Important information could not be identified by ACP1 including patient status on admission, whether $\text{SpO}_2 < 95\%$ occurred or the number of laryngoscopy attempts. Review of videotaped events avoids loss of these details. The AIMS data collection forms completed by ACP1 did not identify lack of clinical examination as a contributory factor. Data collected by these forms may be improved by specific inclusion of a question about clinical examination. No report of this event was made to the Anesthesia Quality Assurance system. The only records of this incident were the words "intubation #1, esophageal intubation" in the anesthesia record.

11.4.3 Conclusions

Prolonged uncorrected esophageal intubation occurred due to three clinical management problems: 1) failure of ACP1 and ACP2 to confirm ET tube placement in the trachea by either clinical examination, or timely analysis of ETCO_2 ; 2) excessive attention to the monitors; and 3) a failure to revise airway management expeditiously despite evidence of clinical deterioration. Revision of management should include clinical examination, ETCO_2 analysis, repeat laryngoscopy, and reoxygenation via mask ventilation.

In addition five system failures occurred including: 1) loud non-task related conversations and laughter from nearby personnel may have interfered with trauma team communications; 2) delegation of the task of auscultation after passage of the ET tube to a non-anesthesia team member whose role and training status was unclear to the anesthesia team; 3) lack of ETCO_2 monitoring capability when the resuscitator bag emergency ventilating circuit was in use; 4) poor team coordination compounded the original error of esophageal intubation with lack of cricoid pressure on extubation of the esophagus; and 5) failure in training of the importance of clinical examination and ETCO_2 analysis immediately after passage of the ET tube.

Recommended Protocol

The optimal sequence of tasks and type of confirmatory tests for correct tracheal tube placement in every clinical circumstance remains unresolved. The checks and communications described in the algorithm (Figure 11.4) are a proposed protocol to confirm correct tracheal tube placement. Refinement of this algorithm may be needed to suit other clinical circumstances such as intubation following cardiac arrest to include

alternative techniques to auscultation and CO₂ analysis that may be used in these other circumstances.

Verbally identifying checks in the algorithm as they are performed may be useful to minimize errors of omission, communicate uncertainties and identify the status of confirmatory checks for correct tube placement. Repetition of these checks and communications by a supervisor or non-intubating ACP, when there is doubt about the correct position of the tube or if continuous exhaled CO₂ analysis with waveform is unavailable, has analogy to the Federal Aviation Administration (FAA) requirements of pilot management in the cockpit (FAA, Feb 1995). A further FAA requirement during take off and landing is the maintenance of a "sterile cockpit" where non task-related communications are avoided. It is possible that the prolonged esophageal intubation described above would have been corrected much earlier if the MS IV's communication about hearing air entry into the stomach had not been drowned by laughter and non task-related conversations from a nearby location. Anesthesia care providers might consider such a "sterile cockpit" recommendation during anesthesia induction and intubation in all non-routine circumstances such as rapid-sequence induction and intubation. It would facilitate the checks and communications outlined in the algorithm and may result in a reduction in the duration of unrecognized esophageal intubations.

Formal video analysis confirms that error evolution and rectification in anesthesiology follows models previously describes for other domains. As such, approaches that have already been described for training, for example in industry and aviation, may also be applicable in anesthesiology (Reason, 1990). It is the detailed documentation of events possible with videotaping that can yield lessons that might otherwise be difficult to discern or obtain from retrospective reports. This report illustrates the complexity of adverse respiratory events such as esophageal intubation. The solution to prevention of respiratory critical events associated with intubation may lie with the development of general protocols or algorithms that can be rehearsed and then expertly applied in complex situations or crises.

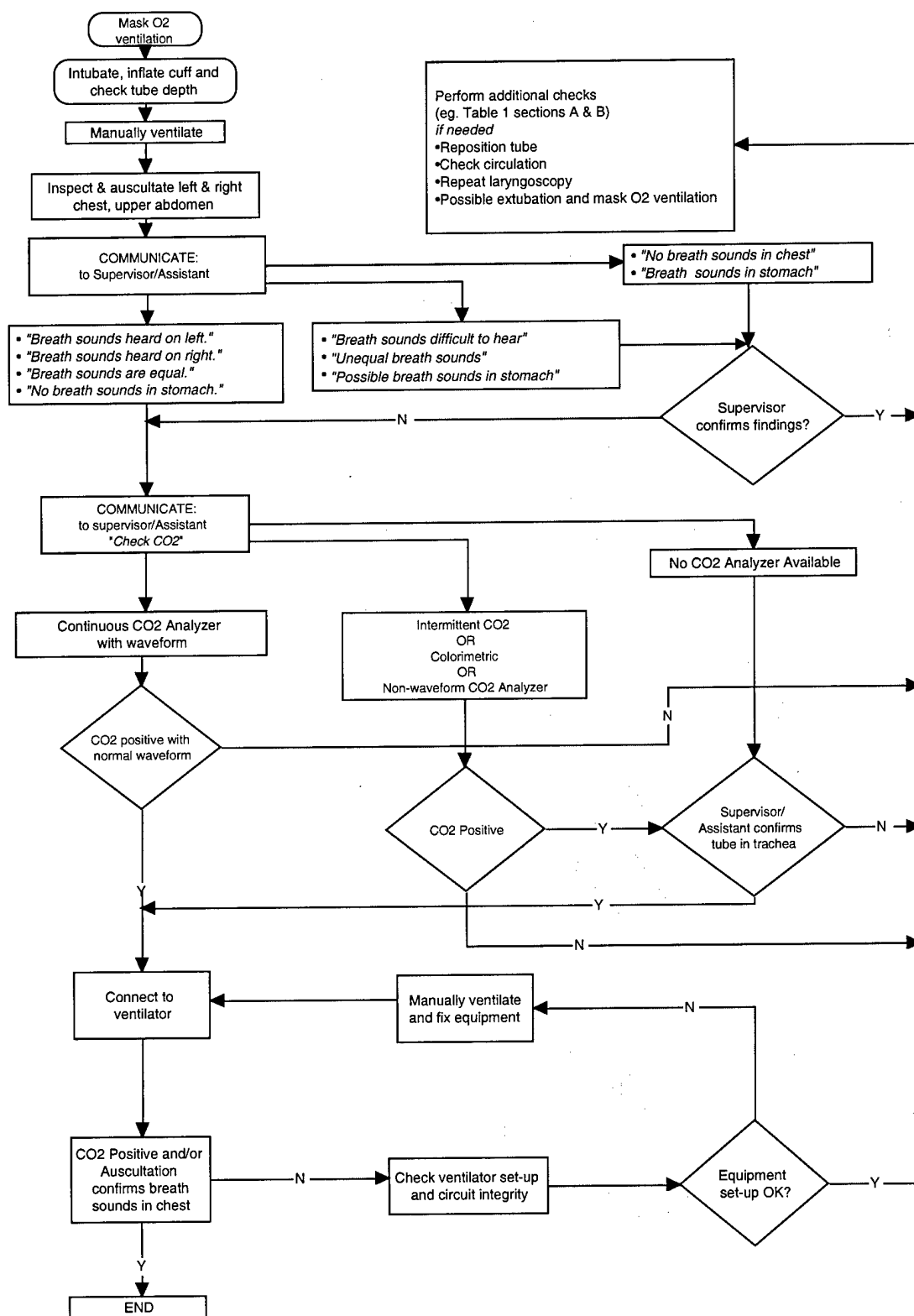


Figure 11.4: Recommended task communication algorithm for airway management.

	SRs (pre)	SRs (dur)
TOs (pre)	0.12	0.19
TOs (dur)	0.02	0.18
DM-Errs	-0.03	0.31

Table 11.1: Pearson r matrix between stress ratings and task omissions and decision-making errors in individual cases.

00:00	Patient arrives in admitting area receiving O2 by resuscitator bag attached to EOA.
00:03	"He's got a pulse"
00:48	IV working in right arm, IV fluids hanging
01:00	Anesthesiologist listens to both sides of chest
01:26	"Blood pressure 98/60"
02:16	Tracheal tube in hands of EMP
03:01	Thiopental 50 mg, succinyl choline 100 mg given IV
03:10	Anterior half of cervical collar off; cricoid pressure applied
03:20	EMP takes over ventilation through EOA from anesthesia fellow
03:27	EMP disconnects resuscitator bag
03:39	Laryngoscope in, "this (EOA) looks like it's in the trachea"
03:45	EMP asks for suction
03:50-3:56	Laryngoscope out; airway suctioned
04:03	Anesthesiologist "Just ventilate him again and take it (EOA) out and change to an ET tube."
04:07	EMP ventilates through EOA
04:32	Cricoid pressure on; EOA cuff deflated
04:45	Repeat laryngoscopy
05:01	EOA out
05:21	Conventional tracheal tube insertion begins
05:33	Tube inserted on third attempt
05:42	Ventilating with resuscitator bag
06:00	EMP listens to both sides of chest and stomach
06:21	Anesthesiologist delegates anesthesia fellow to manage a second patient admission
06:23	Ventilating with resuscitator bag; anesthesiologist measuring distance ET tube in trachea. Listens to chest.
06:45	Anesthesiologist connects ventilator
06:57	Pulls the ET tube back
07:33	Change ventilator setting from pressure support to mandatory ventilation
07:52	ETCO2 monitored
08:36	ET tube taped in place

* For confidentiality and medicolegal reasons, and because it does not change the issues described and discussed, the adult male patients one and two are not further identified.

Table 11.2: Major events and elapsed time (mm:sec) since admission during resuscitation of Case 1 (EOA = esophageal obturator airway, EMP = emergency medicine physician, ET = endotracheal, ETCO2 = end-tidal CO2)

00:00	Patient arrives in admitting area
00:18	O2 mask on
00:35	Ventilate patient by mask and resuscitator bag. Physical examination begins. No recordable BP. Femoral pulse palpated at HR 114/min.
01:02	"Intubate" (Team leader)
01:35	Succinylcholine injected IM into tongue
01:52	CRNA inserts nasotracheal tube
01:57	Gagging noise as nasal tube advanced
02:15-02:55	Repeated patient vomiting out of nasal tube
03:28	IV access achieved via Cordis. HR 145/min
03:56	Team requests "fat boy BP cuff"
04:34	Succinylcholine given IV. Cricoid pressure on
04:39	Patient holding suction catheter pushing anesthesia personnel away
05:19	CRNA manually ventilating patient with bag
05:22	Cordis connected to Level One infuser
05:39	Still no recordable BP
06:38	Intubation
07:21	HR 146/min. Still no BP obtained
08:22	O+ packed RBC 2 units started
10:32	Team complains "we don't even have any BP and the guy's been here ten minutes."
11:20	BP is "over 100 mmHg" (palpation)
11:28	End-tidal CO2 monitored
11:34	HR down to 133/min. Temp monitored = 36 oC
12:39	Another BP cuff placed on right arm
14:04	Subclavian line placed
14:50	BP 110/46 by arterial line
15:18	3L crystalloid, 2 units RBC's, warm plasma given
22:35-30:23	X-rays
29:58	Still rapid infusion. HR 122/min BP keeps drifting down. Bleeding from GSW
30:54	Fresh frozen plasma ordered
31:16	Request made to move to OR as team suspects aorta and vena cava are injured

* For confidentiality and medicolegal reasons, and because it does not change the issues described and discussed, the adult male patients one and two are not further identified.

Table 11.3: Major events and elapsed time (mm:sec) since admission during resuscitation of Case 2 (IV = intravenous, BP = blood pressure, CRNA = certified registered nurse anesthetist, HR = heart rate, O+ = O Rhesus positive, RBC = red blood cells, GSW = gun-shot wound, OR = operating room)

Chapter 12

Team Performance under Stress

In this chapter, we wish to report the results of video analysis of team coordination during stressful situations. We attempt to answer the following two questions: (1) What strategies were used by practitioners to achieve coordinated activities? (2) What was the nature of the situations in which coordination breakdowns were observed? The answer to the first question can provide us with information, for example, on how to design workplaces and interfaces to facilitate team coordination (*e.g.*, Segal, 1994). The answer to the second question can direct us at those challenging situations where team coordination is crucial and is prone to breakdowns, and thus one can target team training accordingly.

It should be reiterated here that the domain of patient resuscitation is a dynamic, complex, and high-risk one, and the teams in this domain often have to function under extreme time pressure and with considerable amount of uncertainty. Thus this environment can be used as a research vehicle to study team performance in stressful and complex task domains that are similar to but not limited to medical domains.

12.1 Task Complexity and Team Coordination

12.1.1 Introduction

Collecting and examining human performance data and cataloging human errors are certainly important in improving the quality of care in emergency medicine. An orthogonal approach is to understand potential mismatches between capacities of individuals and teams and demands of tasks presented to the care givers. One way of predicting task demands is through the investigation of task complexity, a characterization of tasks that describes why tasks are complex to perform. As evidenced by Woods' (1988) treatment of the topic of task complexity, many valuable insights can be obtained by examining the nature of task complexity from the viewpoint of its impact on activities. From previous incident reports, simulator investigations and field studies, Woods synthesized a picture of cognitive demands due to task complexity and plausible ways in which individuals cope with task complexity, particularly during crisis situations. Such a picture can help us in predicting what types of cognitive problems are likely to confront practitioners, and what types of cognitive support are likely to be useful.

Various definitions of the concept of task complexity have been put forward, mostly in the context of well-defined experimental tasks. Three such definitions are described here as examples. For a multiple choice task, Payne (1976) used the number of alternatives as a measure of task complexity. For an inspection task, Gailway and Drury (1986) used the number of different fault types as a measure of task complexity. For a monitoring task, Kennedy and Coulter (1975) used the number of channels to be monitored as a measure of task complexity.

Real life tasks in most situations are a combination of these and other individual tasks, and thus the definition of task complexity is not clear cut. One attempt was by Woods (1988). He proposed a four dimension scheme oriented for tasks in process control environments to define task complexity: dynamic situations, interacting parts, uncertain data, and risk. These dimensions were proposed for the prediction of demands for cognitive activities and not for the prediction of demands for team coordination.

Despite the fact that most tasks in workplaces are handled by a group of people working as a team, little empirical or theoretical work has been reported to characterize task complexity for a team environment. No framework has been put forward to understand what makes coordination of a task complex for a team.

As a first step toward delineating the components of task complexity when team performance is concerned, a study was conducted to contrast the characteristics of one emergency medical procedure observed under two types of circumstances differentiated by task urgency. After the description of the method and results of the study, four components of task complexity are identified that explain *in what ways* the tasks in emergency situations are complex for teams to perform. Based on the findings of the study and the components of task complexity proposed, the implications of task complexity for team coordination are discussed.

12.1.2 Extraction of Data for Studying Task Complexity

Based on a task analysis of tracheal intubation, a review form was designed to extract the following information from review of the videotapes of patient care.

- (1) The patient's status upon arrival, e.g. in hemorrhagic shock or unconsciousness.
- (2) Technical difficulty of intubation: subjective ratings of intubation difficulty, number of attempts before successful intubation, airway suctioning activities, and time of connecting the ET tube to a mechanical ventilator.
- (3) Patient physiological monitoring information available during the course of intubation.
- (4) Pace of work: the tasks accomplished before intubation (out of 15 in total) and duration of intubation.

The form included 29 items of multiple-choice questions, checklists, and timings of specific events for intubation. Anesthesia care providers experienced in tracheal intubation were asked to review the videotaped intubation and fill the review form. Interrater reliability was assessed by intraclass correlation coefficient (Shrout & Fleiss, 1979).

12.1.3 Analysis

The cases were divided into two categories according to how urgently intubation was needed: *high-urgency intubation*, performed within 10 minutes of the patient's admission, and *low-urgency intubation*, performed 10 minutes after the patient's admission. This division was used to contrast tasks with different levels of time pressure exerted on the care givers. Unidirectional χ^2 tests were used for comparing frequencies of occurrence and proportions of the tasks accomplished, and t-tests were used for comparing time durations.

12.2 Results

Over 100 cases were recorded during the period of 3 years, 48 of which showed intubation performed by 21 different anesthesia care providers. Among the 48 intubation procedures, 17 (35%) were high-urgency intubation. These all occurred in the patient admitting areas. Among the low-urgency intubation procedures, 15 occurred in the admitting areas, and 16 in the operating rooms. A total of 11 different videotape reviewers were used. The average number of reviewers for each case was 2.7. Intraclass correlation coefficients ranged from moderate (.57 for the question of "intubation rated as very difficult") to excellent (.99 for the question about the timing of events).

Figures 12.1 and 12.2 summarize the results of comparison of patient status upon arrival, available monitoring information, technical difficulties, and pace of work between the two types of intubation procedures. All comparisons were statistically significant at $p < 0.05$.

The patients requiring high-urgency intubation were significantly more likely to be in hemorrhagic shock (33% versus 0%), and they were more likely to be unconscious (69% versus 7%) than were those requiring low-urgency intubation. The amount of patient monitoring information available was significantly less during high-urgency intubation than during low-urgency intubation, shown by the availability of four important sources of monitoring information (Figure 12.2). Tasks were technically more difficult in high-urgency intubation, as reflected in four of the comparisons in Figure 12.1: (a) high-urgency intubation was more likely to be rated as "very difficult" than was low-urgency intubation (33% versus 7%); (b) high-urgency intubation was more likely to require multiple attempts before success (41% versus 20%); (c) Airway suctioning was more likely to occur in high-urgency intubation (56% versus 17%); and (d) High-urgency intubation took longer than in low-urgency intubation for the anesthesia care providers to connect the ET tube to the mechanical ventilator (44% versus 94% connected within 4 minutes). The duration of high-urgency intubation was significantly shorter than that of low-urgency intubation (252 seconds versus 420 seconds). More tasks were omitted in carrying out high-urgency intubation than low-urgency intubation (26% versus 14%).

12.3 Components of Task Complexity

The findings from the study suggest that when carrying out high urgency tasks, the anesthesia care providers had to take care of patients whose condition was more critical

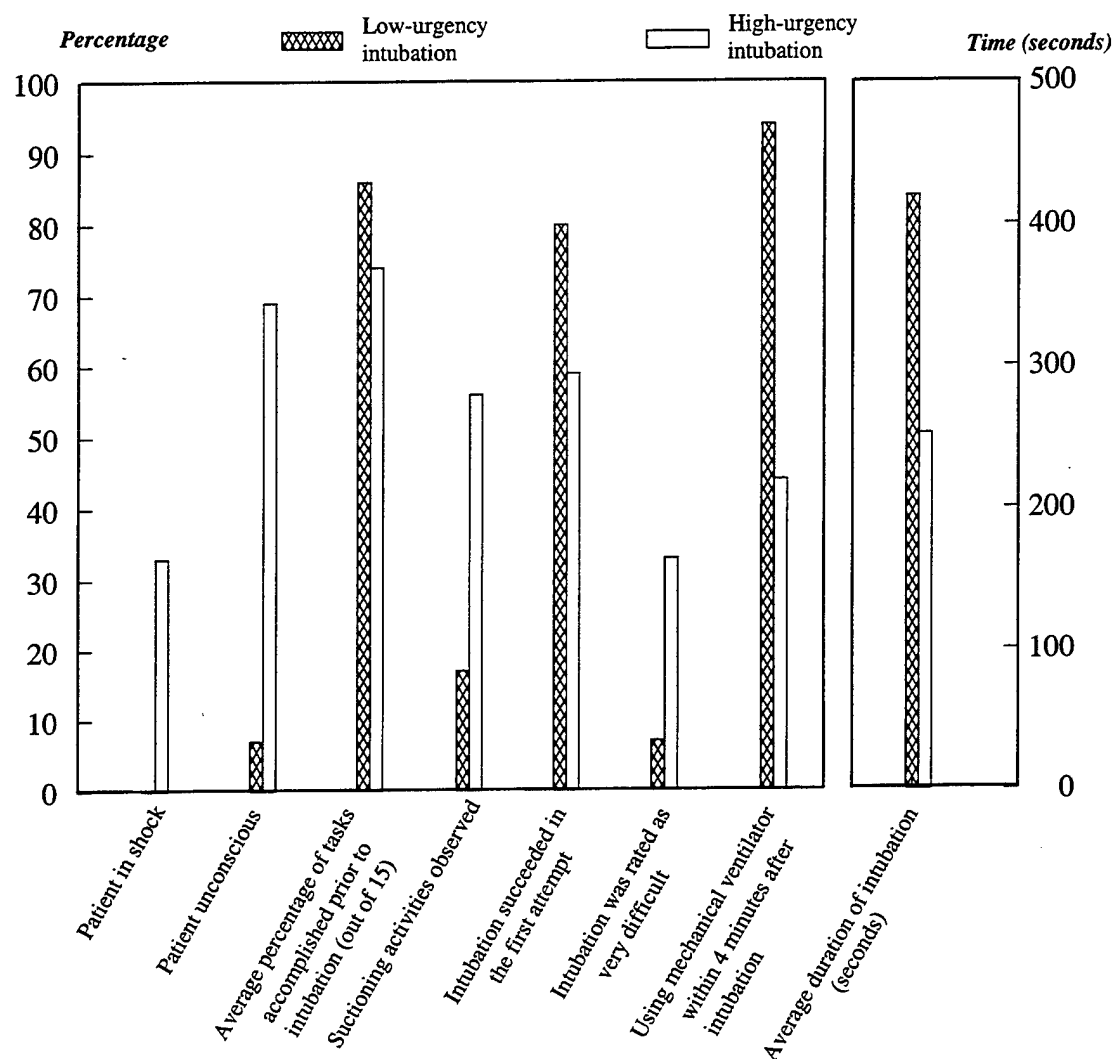


Figure 12.1: Comparison of two types of intubation: high versus low urgency. Unidirectional t-test was used for duration comparison, and χ^2 -test for proportion and frequency comparison. All comparisons listed here are statistically significant at $p < 0.05$.

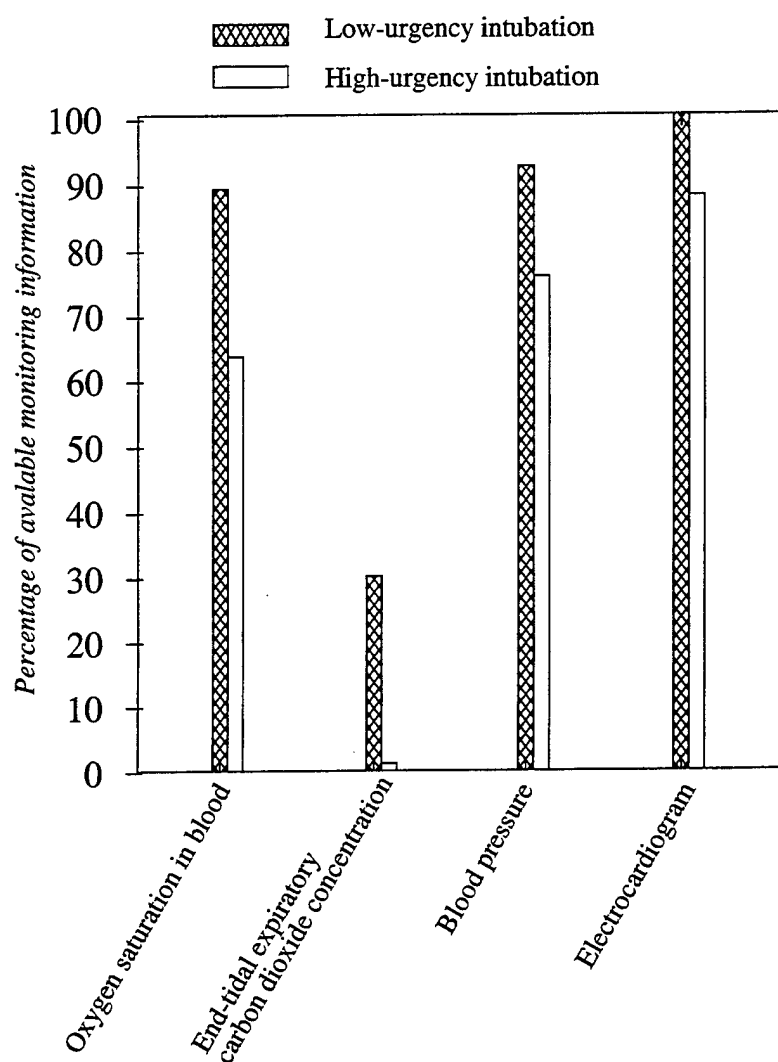


Figure 12.2: Monitoring information available during low and high urgency intubation. χ^2 -test was used to compare the frequencies listed here. All comparisons were significant at $p < 0.05$.

with less monitoring information available, and they accomplished tasks that were more difficult at a faster pace.

Based on the comparison of the task characteristics of low- and high-urgency intubation, four components of the task complexity facing emergency medical teams can be identified: (1) multiple, concurrent tasks, (2) uncertainty, (3) changing plans, and (4) compressed work procedures and high workload.

Multiple, Concurrent Tasks

As one would expect and shown by the data presented here, patients were more likely to be in hemorrhagic shock when they required high-urgency intubation. For a patient in hemorrhagic shock, achieving intubation was only one of the immediate resuscitation objectives. Other equally important objectives were simultaneously required, such as normalization of vital signs and restoration of adequate blood circulation. Therefore while the anesthesia care providers were carrying out intubation, other members (*e.g.*, the surgeon) of the resuscitation team would concurrently complete other essential tasks.

Uncertainty

During high-urgency intubation desirable monitoring information was often unavailable even though it was routinely available during low-urgency intubation (Figure 12.2), although the same monitors were available regardless of task urgency. Several factors contributed to the decreased use of patient monitoring information during high-urgency intubation. One factor was that often there was simply not enough time for the care givers to set up the desired monitors. This was suggested by the finding that more tasks, some of which were monitor setups, were omitted in high-urgency intubation than in low-urgency intubation. The second factor was that even when the team attempted to set monitors up, many patients were uncooperative and even combative (due to impairment of consciousness which was more frequent in the patients requiring high-urgency intubation; see Figure 12.1). This non-cooperation led to difficulties in placing and in maintaining patient sensors in the correct position needed for successful monitoring. A third reason was that the condition of some patients was so unstable (*i.e.* in cardiac arrest) that some of the monitoring information could not be obtained reliably.

The amount of information obtained through direct, clinical assessment was also often reduced in high-urgency intubation. Due to the high percentage of unconscious patients in high-urgency intubation, it was often difficult for the resuscitation team to collect critical information about the patient, such as medication, past medical history and mechanisms of injury. Another indication of reduced clinical information was the obstructed view during airway management indicated by increased occurrences of suctioning activities needed because of the presence of secretions or blood. (refer to the task description above).

Changing Plans

The findings of this study indicate that tasks were more likely to require multiple attempts and were more difficult when task urgency was high. These aspects of task

characteristics suggest that emergency care givers often had to consider and switch to alternative plans. For example, when intubation was very difficult, anesthesia care providers had to consider alternative, contingency plans to ensure adequate ventilation (such as establishing a surgical airway through the neck).

Compressed Work Procedures and High Workload

The finding that the duration of high-urgency intubation average only about half as much as that of low-urgency intubation (Figure 12.1) indicates hastened work procedures. In addition, extra steps often had to be performed in emergency situations. Such extra steps were suggested by three of the findings of the study.

First an increased need for suctioning was found in high-urgency intubation. Suctioning of the patient's airway slows down the intubation process and adds to the workload of the anesthesia care providers. Second, the use of a mechanical ventilator after high-urgency intubation was delayed when compared to low-urgency intubation. Manual ventilation occupied the much needed attention that could be available for other essential tasks if a mechanical ventilator is used. One explanation for the delayed use of a mechanical ventilator is that the integrity of the patient's lungs is usually closely evaluated by manually ventilating the patient. This is necessary because chest X-rays and other evaluations may be incomplete during the early stage of resuscitation when intubation was urgently needed. Another factor is that high-urgency intubation is often performed when multiple personnel are around the patient performing other tasks, which makes it difficult for anesthesia care providers to connect the ventilator. Thirdly, the study found an increased proportion of unconscious patients among those requiring high-urgency intubation. Extra steps are often necessary in caring for unconscious, semi-conscious, or combative patients as it is difficult for the resuscitation personnel to get cooperation from the patient.

12.4 Implications for Task Complexity in Team Environments

As pointed out by Hackman and Morris (1975), the performance of a team depends on the ability of a team to coordinate its members' capabilities and efforts. Special skills and efforts are needed to synchronize individual members' activities. Fleishman and Zaccaro (1992) summarize such needs in a taxonomy of team functions, which include monitoring of each others' activities and distribution of task workload.

A number of strategies are available for emergency medical care personnel to coordinate and to fulfill some of these team functions. First of all, established work procedures, as pointed out by Boguslaw and Porter (1962), dictate much of the team functions. For instance, the protocol of the so-called "ABC" or airway, breathing, and circulation used in resuscitating cardiac arrest patients, specifies goal and action priorities for resuscitation personnel. Secondly, similar to other medical settings, extensive on-job training and experience in emergency medical care provide personnel with the ability to anticipate the needs of others and what they will do next without explicit (*i.e.*, verbal and gestural) communications. Thirdly, in emergency medical care settings, care givers have continuous visual and auditory contact with each other. (Similar observations were made by Hutchins, 1995, about ship navigation teams.) Team members share the same work

space and event space (*i.e.*, what was happening). They can sense, through shared work space and event space, what others are doing or intend to do. A wait-and-see strategy, for example, can be very effective in avoiding potential conflicts among several people in access to the patient and equipment. However, task complexity in emergency medical care could reduce the effectiveness of these coordination strategies.

In the following the implications of task complexity are discussed in terms of task complexity components identified earlier.

Multiple, Concurrent Tasks

When multiple tasks are attempted concurrently, one of the challenges facing emergency care personnel is to resolve various potential conflicts among the members. The team is prone to problems in team coordination, such as goal conflicts, task interference and competitions for access to the patient.

For example, the intubation procedure usually requires paralyzing the patient (see task description above), but patient paralysis can make other team members' tasks (*e.g.*, neurological examinations) difficult or impossible. When the patient's condition is critical and an intubation has to be carried out, conflicts can arise between the anesthesia care provider's activities and other care givers.

Unlike many other emergency settings (*e.g.*, the emergency management center studied by Moray, Sanderson, and Vicente, 1992), emergency medical personnel have to share limited working areas around the patient. In particular, access to the patient is necessary for many tasks, both for clinical monitoring (*e.g.*, attaching patient sensors) and for treatment (*e.g.*, stopping hemorrhage). Multiple, concurrent tasks create potential challenges for care givers to coordinate the limited patient access among the team members.

Uncertainty

Patient monitoring is an important part of resuscitation that helps to reduce unknown information about the status of the patient and increases the clinician's ability to judge the effect of a treatment. For example, the monitoring information about the patient's exhaled carbon dioxide is often used to determine whether an intubation is successful. The lack of a functional monitor for such information increases the difficulty of verifying the position of the endotracheal tube.

When the physiological status of the patient is uncertain, what the team needs to do can become ambiguous. Conflicts can arise in perception of the tasks that need to be accomplished. As a result, it can be a challenge for a team to achieve one of the important team functions: anticipating other team members' material and information needs. (See team function taxonomy in Fleishman & Zaccaro, 1992.)

Changing Plans

When alternative plans are to be executed, the team may be challenged to form a coherent understanding of when to switch to what alternatives and how tasks are to be distributed, especially when the transition to the contingency plans occur suddenly and under time pressure.

In one of the videotaped cases previously reported (Mackenzie, Craig, Parr, Horst, and the LOTAS Group, 1994), under the pressure to perform a difficult intubation, two anesthesia care providers changed to alternative approaches without informing each other. Unfortunately, each took a course of action conflicting with that taken by the other. Furthermore, the rest of the team was unable to provide timely support as they seemed to have difficulties in understanding what alternatives were initiated or how to coordinate their assistance.

Compressed Work Procedures and High Workload

High workload under time pressure creates challenges not only for individuals but also for all resuscitation personnel to coordinate activities. They may have to deviate from traditions and usual procedures and skip certain tasks in favor of more critical tasks. Such a strategy can create ambiguity in terms of which steps should be skipped and how a team should reorganize its members' activities when often-adopted procedures are not followed.

12.4.1 Coping with Complexity

A number of approaches can be suggested to help teams in emergency medical care cope with task complexity. One approach is training in team coordination. Current training for patient resuscitation personnel in the center studied is primarily oriented towards medical and technical aspects, and not specifically towards the skills of performing in a team environment. Training in explicit communication should reduce the occurrence of failures in team coordination. For example, when novel approaches are adopted or established procedures are modified by the leading members of a team, verbalization can help the rest of the team orient and prepare themselves. Team training in resource management and attitude changes have been advocated for highly skilled teams during crises (*e.g.*, Foushee & Helmreich, 1988; Howard et al, 1992) and in routine surgical operations (*e.g.*, Helmreich & Schaefer, 1994). Although such training is important and needed for teams in emergency care (*e.g.*, Donchin et al, 1995), task complexity poses challenges that require more than changes in attitude and use of resources. Training in explicit communication is needed for the purpose of team coordination to improve team performance in emergency care.

Designing work procedures is another approach to reduce the impact of task complexity, considering that in emergency medical care, few procedures are formalized and enforced. Boguslaw and Porter (1962) found that work procedures play an important role in team coordination. Work procedures can be designed to reduce the ambiguity in terms of task distributions and increase the ability of team members to provide timely assistance in crisis situations. Work procedures can also be used to make certain verbalization

mandatory, which can help the team function in situations such as when contingency plans are executed.

12.5 Conclusions

By comparing the task characteristics of one medical procedure at two levels of task urgency, the study reported here suggests several ways in which tasks in emergency medical care are complex: the condition of patients is often critical; the care givers sometimes have to deal with great uncertainty and high workload; and tasks are often technically difficult and executed at fast pace. Procedures that can be carried out sequentially in low-urgency situations often have to be carried out concurrently when task urgency is high. Uncertainty can create discordance in perceived tasks and priorities. The failure or extraordinary difficulty in performing a procedure can induce that adoption of contingency approaches that are novel to some of the care givers. The established or often-adopted solutions may have to be modified or abandoned due to high workload.

Based on the findings of the study, four components of task complexity in emergency medical care were identified: multiple concurrent tasks, uncertainty, the presence of contingency plans, and compressed work procedures with high workload. These components of task complexity in emergency medical care pose challenges for team coordination and increase the potential of breakdowns in team coordination, such as conflicts in access to the patient, goals, and tasks. Two approaches are suggested to help care givers in emergency medical care to cope with task complexity: training in explicit communications, and design of work procedures to facilitate team coordination.

Chapter 13

Team Coordination Strategies

13.1 Method and Materials

13.1.1 Data Processing and Video Analysis

A wealth of information was contained in the video recordings. It was possible to conduct many types of analyses on the video recordings. Our team coordination analyses were focussed on the following two objectives: (1) discovering the ways in which team coordination was achieved, and (2) finding out the nature of breakdowns in team coordination. The critical incident technique (Flanagan, 1954) was adapted, and team coordination was examined in the following three types of critical incidents: decision points, high workload periods, and apparent problems in team coordination.

The video tapes were reviewed by a group of analysts comprising domain experts and cognitive scientists. For the purpose of detailed examination of team activities during critical incidents, the verbal communications and SMEs' commentaries in 16 cases were transcribed. Through time stamps, the transcriptions were merged with the descriptions of major events, significant patient physiological measurement of vital signs, and observable activities of the team. Despite capturing only part of the events and activities on the video tapes, this time-line merged data turned out to be very useful in testing explanations for the critical incidents, and was much easier to manipulate and access than raw video data. Figure 13.1 shows a sample of the analysis results of verbal communications.

13.2 Strategies of Coordination

The findings on the ways or strategies used by resuscitation teams to coordinate will be presented. Findings regarding breakdowns in coordination will be described in the next section.

From the cases we analysed, verbal communications occurred rather sparsely (see the sample data in Figure 13.1), in comparison with the busy activities and the degree of uncertainty and complexity of resuscitation. In addition, it appeared that much of the verbal communications was associated with requesting materials and help, and only a small portion was related to problem solving (such as planning and diagnosis). The

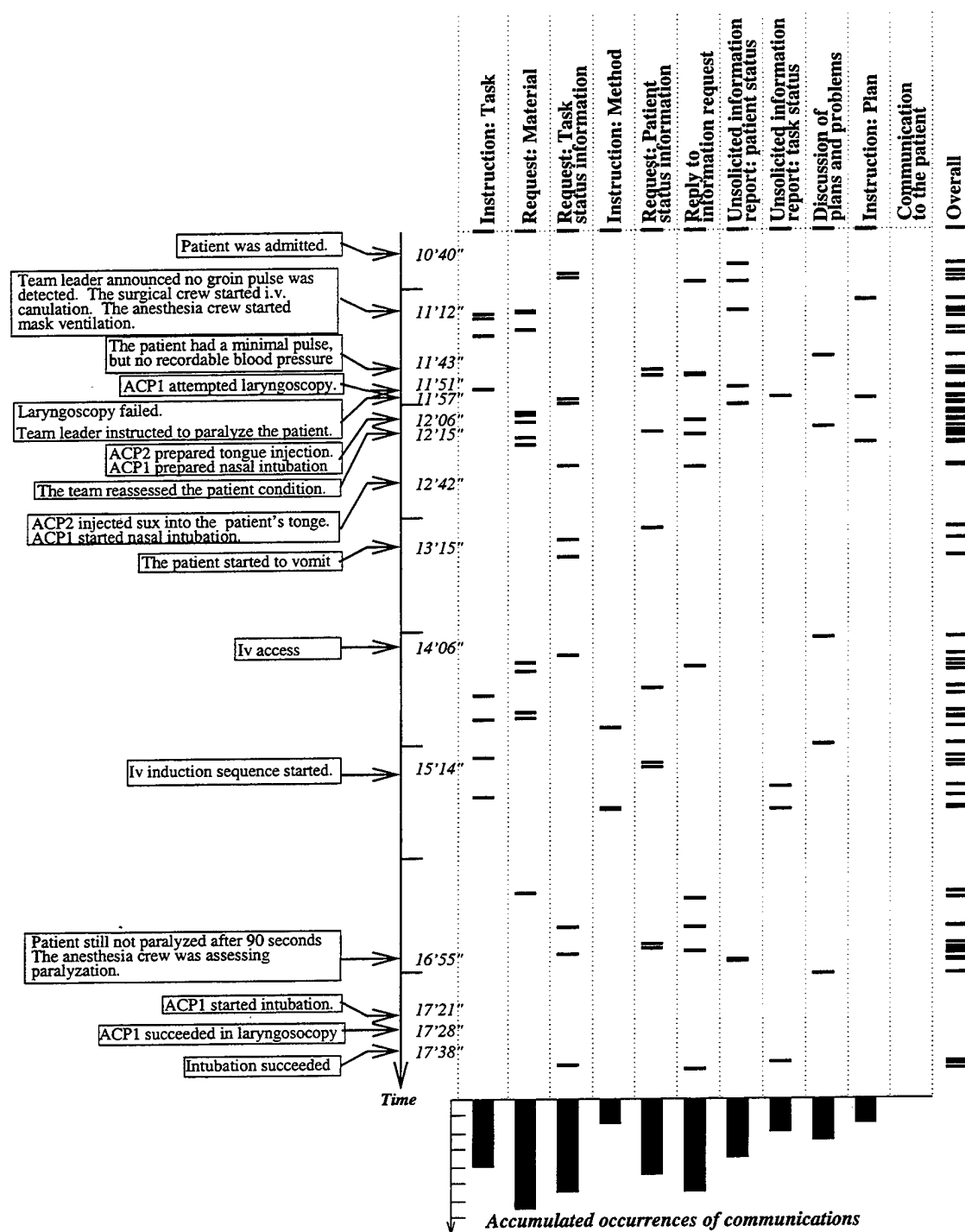


Figure 13.1: Sample analysis results of verbal communications. Each communication is shown by overall occurrence (right column) and categorized in the other 11 columns, using horizontal bars to depict their timings. The left column provides the time code, and key events are described on the vertical axis. The horizontal axis shows a histogram summarising the relative number of communications by category between patient admission time and successful intubation. ACP: anesthesia care provider, IV: intravenous.

findings related to coordination strategies that were used by resuscitation teams are reported in two separate areas: *task coordination*, or the distribution and delegation of tasks, and *information flow*, or the passage of information regarding patient status and contingency plans.

13.2.1 Task Coordination

During the course of resuscitating a trauma patient, many physical tasks were performed. Some of them had to be coordinated among team members within a crew or across crews. This was so either because the tasks needed synchronous effort from multiple people (e.g., lifting the patient), or because the tasks relied on preconditions (e.g., suctioning equipment must be ready before usage), or because multiple tasks need to be accomplished within a short period of time (e.g., establish the airway and restore blood circulation).

Several forms of non-communication task coordination activities were noted in video analysis. Five of them are listed below.

- *Following the protocols.* Established practices (sometimes codified as protocols, such as the Advanced Cardiac Life Support or ACLS protocol), specify task distributions and priorities, immediate goals, and problems to be treated. The tasks to be done by each team member are clear. Without much communication, in almost every case, the surgical, anesthesia, and nursing crews commence their activities after the patient arrived. We observed clear task distributions among the crews in resuscitation teams at the beginning of each patient admission, despite the uncertainty about the patient's status.
- *Following the leader.* Team or crew members determined what they should do by watching the crew leader. The activities of the crew leader can be viewed in some sense as the "medium" through which the team leader passed information (such as instructions) to the rest of the team. If not occupied, we observed that team members tended to follow the attention foci of team leaders. Needed materials or help were provided often without explicit solicitation.
- *Anticipation.* The team members were also found to provide unsolicited assistance through the anticipation of the team leader's response to the patient's physiological events. A gagging sound, in one case, led an assistant to offer a suctioning catheter in anticipation that the patient would vomit soon and the anesthesia crew member would have to use suction to clear the patient's airway. Thus the shared physical event space became a medium of communication for the team. The prerequisite, of course, was the ability to understand the significance of patient events. The workspace itself is also a medium through which the teams coordinate. We often observed that team members, while not under instruction to perform specific tasks, scanned the workspace and perceived tasks needed to be carried out. In one case, for example, upon seeing an unopened package which would be used soon, a team member began to open the package and set up the device inside the package.
- *Activity monitoring.* The interdependencies of tasks shared by a team mean that one member's tasks could sometimes only commence after the success of another member's tasks. (For example, surgeons can only begin certain procedures of resuscitation after the patient is anesthetised.) Thus monitoring the progress of an

other member's tasks not only made it possible to compensate for a teammate's performance, but also gave lead information to prepare for the next step.

In many cases, the surgical crew did not announce their plans, however, the anesthesia crew inferred what needed to be done from the activities of the other crew. For example, during the review of the video tapes of a case, one participant in that case revealed that the conversation between two surgical crew members provided cues of what the surgical crew would do next, even though the conversation was not directed at the anesthesia crew.

These strategies of task coordination, without the use of explicit, verbal or gestural, communications, enabled the resuscitation teams to perform smoothly in most situations.

13.2.2 Information Flow

One of the most interesting aspects of team coordination is the explicit, verbal communications regarding situational assessment and future plans, even though, as indicated in Figure 13.1, such communications were relatively rare. In the situations where such information flow was detected, we found most of them had clear indications that the team was at a decision point. The team members voluntarily provided their views of the situation based on the decisions that the teams were facing at the time. For example, in one case (see Figure 13.1) when the patient was still not paralysed 90 seconds (the usual duration) after the injection of drugs, several team members, without request, provided their assessment of the patient condition and of the reasons why the patient had not been paralysed. In another case, while an anesthesia care provider was determining whether the patient was receiving oxygen, the surgeon provided his assessment of the situation unsolicited by saying that "the patient was stable."

The amount of verbal communications varied greatly among different teams. Some team leaders verbalized their plans clearly while other team leaders let the team members to infer their goals and intentions through actions. The training traditions in medical practices demand little in the areas of leadership style and little studies were reported on how leadership style influenced the information flow within a team. Although advantages of explicit communications of strategies, contingency plans, and decisions seemed to have helped teams, no quantitative measures were developed to study the relationship between performance and leadership styles.

As an example of illustrating the flow of verbal communication, Figure 13.2 is the flow patterns in terms of communication pairs: who is talking to whom. The trauma nurse, labeled as NN in the figure, had more communication links to both the surgical anesthesia and members of the team than anyone else in the team. Even though during the case segment depicted by the figure the nurse had few physical activities, she was at the center of information exchange and performed the task of coordination.

13.3 Coordination Breakdowns

Considering the uncertainty and task difficulties involved in trauma patient resuscitation, the team coordination was adequate in the majority of the cases we analysed. However,

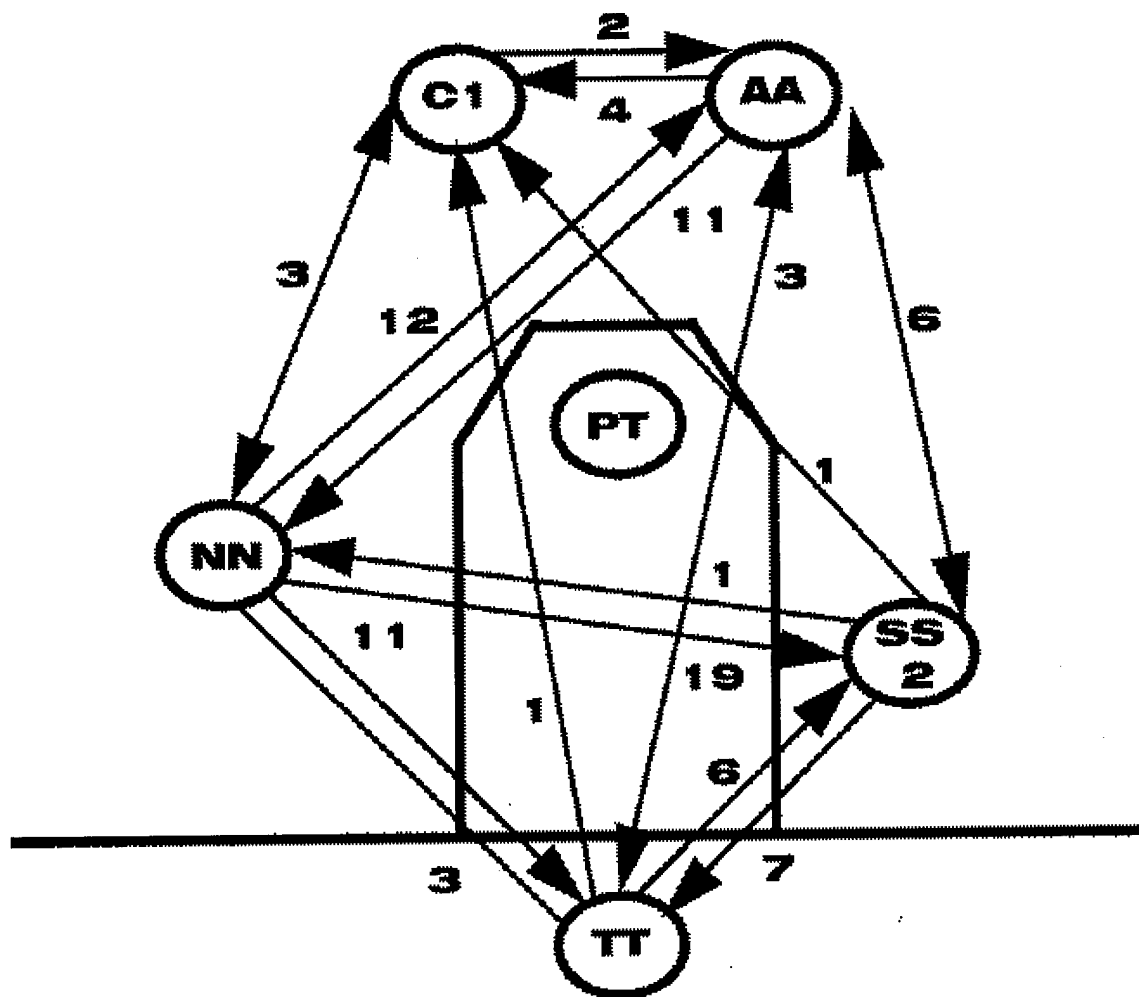


Figure 13.2: Flow patterns of verbal communication. AA: Attending Anesthesiologist; C1: Certified Registered Nurse Anesthetist; NN: Trauma Nurse; PT: Patient; SS: Surgeons (2); TT: Emergency Medicine Technician. The arrows indicate the direction of verbal communications; and the numbers accompanying the arrows are the numbers of discernable verbal communication transactions. The data were from one case segment of about 10 minutes immediately after the patient was admitted for crushing injuries to the lower extremities and pelvis. The layout of personnel was according to actual positions during the case segment.

breakdowns in team coordination were observed in a number of crisis situations. We will report these breakdowns in the following three types of situations: (1) when there was pressure to seek alternative solutions, (2) when an unexpected, non-routine procedure was initiated, and (3) when there was a diffusion in responsibility.

13.3.1 Pressure to Seek Alternative Solutions

In this type of situation, extreme difficulties or unexpected patient responses were encountered and prevented the implementation of routine procedures. When the patient condition was deteriorating rapidly, the team was under pressure to find an alternative solution and to act immediately. Figure 13.3 illustrates one such incident. In this case the patient had a gun shot wound to the lower abdomen. The patient's condition required immediate intubation (the passage of a tracheal breathing tube) to enable controlled ventilation, which required paralysing the patient. The regular route to achieve this for the anesthesia crew was to wait for the surgical crew to gain venous access to the patient (phase A), as drugs to paralyse the patient were usually injected intravenously. However, difficulty in achieving this (due to previous use of veins for intravenous drug abuse) and rapidly declining patient conditions (unrecordable blood pressure, weak pulse, and combativeness due to agonal status) forced the anesthesia crew (with two members, ACP1 and ACP2) to examine alternatives.

During phase B (which represented a length of 20 seconds), the two anesthesia crew members implemented a line of action conflicting with each other's action. No attempt was made by either anesthesia crew member to communicate the problems or discuss action plans during this phase. The intentions and the objectives of each anesthesia crew member could only be inferred after their action plans were started.

13.3.2 Initiation of Unexpected, Non-Routine Procedures

This type of incident arose when unexpected non-routine and novel solutions were attempted. During phase C in Figure 13.3, for example, one of the anesthesia crew members decided to use a non-routine method (blind nasal intubation) of achieving airway access. This method required special materials that had not been anticipated in advance by the supporting members of the team. No announcement was made about the adoption of the non-routine method. As a result, the ability of the supporting members of the team to provide assistance was compromised. Coordination breakdowns in this type of incident were marked by the lack of anticipatory help from the team members, delays in preparing materials, and unnecessary pauses in the team leader's activities to obtain assistance.

13.3.3 Diffusion in Responsibility

In critical circumstances during patient resuscitation, a diagnostic procedure or a treatment plan may have to be abandoned if the patient condition is too unstable. Such changes in plans occur during crises and under great time pressure. The team may have difficulties in adjusting itself from a diagnostic mode to action mode. Figure 13.4 shows one type of such scenario. During phase A, the anesthesia crew (labelled as ACP in

Figure 13.4) concentrated on determining a critical task condition (whether or not the patient's lungs were being oxygenated), during which time the surgical crew (S) was assessing the patient condition and the nursing crew (N) was standing by, ready to provide assistance. After about 5 minutes the patient condition became critical (due to the lack of oxygen input), and the anesthesia crew decided to abort the process of obtaining further diagnostic cues. A sudden change of action (removal of the endo-tracheal tube or ET tube) was taken, without informing the rest of the team in advance during phase A. The inability of the rest of the team to anticipate this sudden change in plan prevented them adjusting their responsibilities accordingly, and resulted in the omission of a critical step (applying cricoid pressure to prevent regurgitation of stomach content into the lungs after the tube was removed).

13.3.4 Summary of Strategies for Team Coordination and types of coordination breakdowns

To summarize the strategies of team coordination, verbal communications can be viewed as one of many media that the team used to communicate. These types of media include, in addition to utterance and explicit gestures, (1) activities, (2) work space, (3) events, (4) foci of attention. These media were possible because team members worked in closed physical work spaces. Although not sufficient in all occasions, they provide an efficient means for the team to coordinate.

The coordination break downs that our video analysis identified can be described in the following four forms: (1) conflicting plans, (2) inadequate support in crisis situations, (3) inadequate verbalization of problems, and (4) lack of task delegation. Their occurrence indicates gaps between what was needed and what the team had done in terms of team coordination.

13.4 Discussions

The video recordings in our study show that team coordination was achieved in most situations with minimum explicit, verbal communications. When team coordination broke down, it often occurred in situations where there was a lack of explicit communication. In the following, we evaluate these findings against three previous studies done by Serfaty et al (1993), Orasanu (1990), and Segal (1994).

In studies of team coordination patterns under stressful and unstressful situations, Serfaty et al (1993) found that high performance teams were able to adapt their coordination strategies in stressful situations to reduce the cost of explicit communications. It appears that the teams in our study had adapted to the implicit coordination due to the high workload in many situations. Although no quantitative comparison was made between high stress and low stress situations, our observations show that in non-stressful situations, verbal communications contained considerable amount of non-essential information, some of which did not relate directly to the case involved. Such an adaption could probably be better explained by the adaption of workload management, as described by Sperandio (1971) in his analysis of communications between air traffic controllers and pilots.

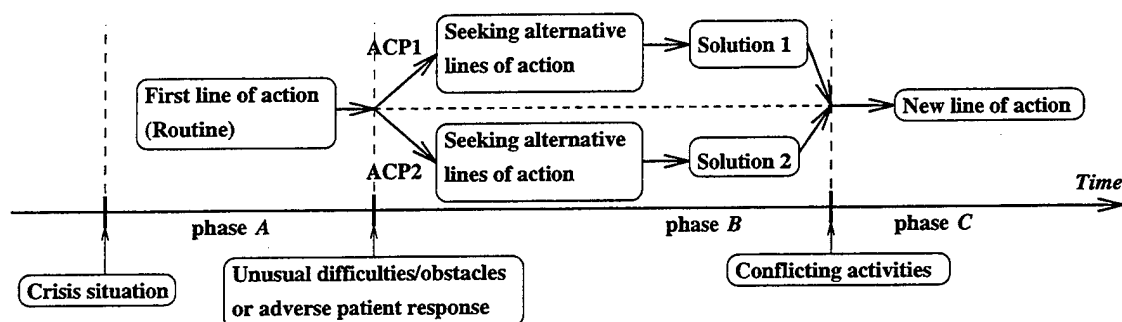


Figure 13.3: Coordination breakdowns when team encountering unexpected obstacle(s). Two anesthesia care providers are labeled as ACP1 and ACP2.

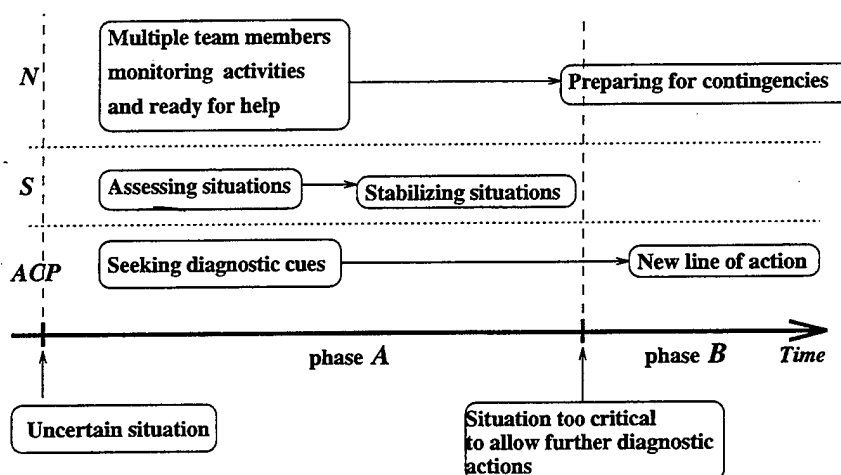


Figure 13.4: Coordination breakdowns when a sudden change of action occurred. N, S, and ACP represent three lines of activities of the nursing, surgical, and anesthesia crews, respectively.

Orasanu (1990) also contrasts team activities between high and low performance teams. Her major finding was that the content of communications was different between high and low performance teams. High performance teams communicated explicitly about problems and plans. However, the small amount of verbal communications in the cases that we recorded did not allow us to compare across different scenarios.

Segal's study (1994) of non-verbal communications had similar findings to ours. He found that visual monitoring of team mates' activities was an important part of team coordination. Through the analysis of visual checking patterns, Segal provided quantitative data to support the notion that visible activity is an essential part of team work.

There are several implications of our findings for workplace design. Similar to what Segal (1994) argues, one has to beware of implicit communication channels, as they had important roles in team coordination in our studies. Practitioners utilized various non-verbal media for coordination: through activities monitoring and through shared event space. These media have important functional roles, including allowing team members to compensate for team mates and to schedule their own activities. The ability to monitor on-going activities and events also enable the team to have a coherent shared mental models (Cannon-Bowers *et al.*, 1991; Orasanu, 1990), thus team member could provide needed information and support without an explicit request.

Our findings also provide guidance to studies of team activities in simulated environments. On the one hand, the current study highlights the importance of non-verbal communications and various types of medium used in communication. Stripping these methods of communication away in a laboratory study, for example, could dramatically change how a team coordinate and impose extra workload on the team. Consequently, the problems in coordination observed in such a simulated setting may have a very limited validity in settings like emergency rooms. On the other hand, the three types of scenarios where coordination breakdowns were observed could lead investigators to focus on these scenarios and understand more about coordination breakdowns.

13.5 Conclusions

In analyzing team performance retrospectively, with or without the aid of recording media, one may tend to look for the break downs in team coordination. But the question of how it is possible for a team to coordinate in complex, dynamic work environment should also be addressed. We believe that in order to understand breakdowns, we should first understand how team coordination can be achieved at all. Only with such a background can we understand how a team should coordinate, and why in some cases coordination breaks down.

Resuscitation teams use non-verbal ways to achieve coordination in most situations efficiently. Breakdowns do occur, however, when unexpected obstacles arise, or novel solutions are adopted, or changes in plans occur, particularly during crisis situations and under extreme time pressure. We should acknowledge the advantage and the important role of non-verbal media that team members could use in their coordination (Cf. Segal, 1994), while at the same time be aware that explicit, verbal communications are crucial in certain situations. The training of teams could target those situations where

communication is essential and they may improve team coordinations in crises.

Chapter 14

Models of Decisionmaking

14.1 The Importance of Clinical Cues

14.1.1 Introduction

During the analysis of videotapes, a hypothesis was formed that a critical skill of decisionmaking in patient management is diagnosis and the successful deployment of that skill relies on clinical cues. Once a diagnosis is made, what needs to be done is often straightforward.

We conducted a test of this hypothesis by comparing decisionmaking in a real life case and simulation recreation of the case.

Methods

The real videotaped critical events were recorded as part of a larger study examining real-life decision-making under stress and were previously extensively analyzed and reported by Mackenzie et al (1994).

Figure 14.1 shows the flow of the critical events along with the ideal action sequence. The videotape showed management of an unconscious patient after admission to a trauma center. During airway management two critical events occurred: insertion of the breathing tube too far into the airway so that only one lung is ventilated (endobronchial intubation) and a failure of mechanical ventilation of the patient caused by a faulty ventilator setting. Two full-mission anesthesia simulators (CAE Electronics Inc. and LORAL) were used to re-create the original case. The differences between these two simulators were transparent to the participants and were in computer models and other devices re-creating the pharmacological and physiological responses to interventions. Six instructor/actors in the simulator were trained using a script of the real communications transcribed from the original videotape. A training session one month before the simulation discussed re-creation of the event and carried out practice on the CAE simulator. On the night before the simulation all six instructors/actors performed each scenario several times on both the CAE and LORAL simulators.

Participants voluntarily signing up to manage the critical incident were randomly assigned

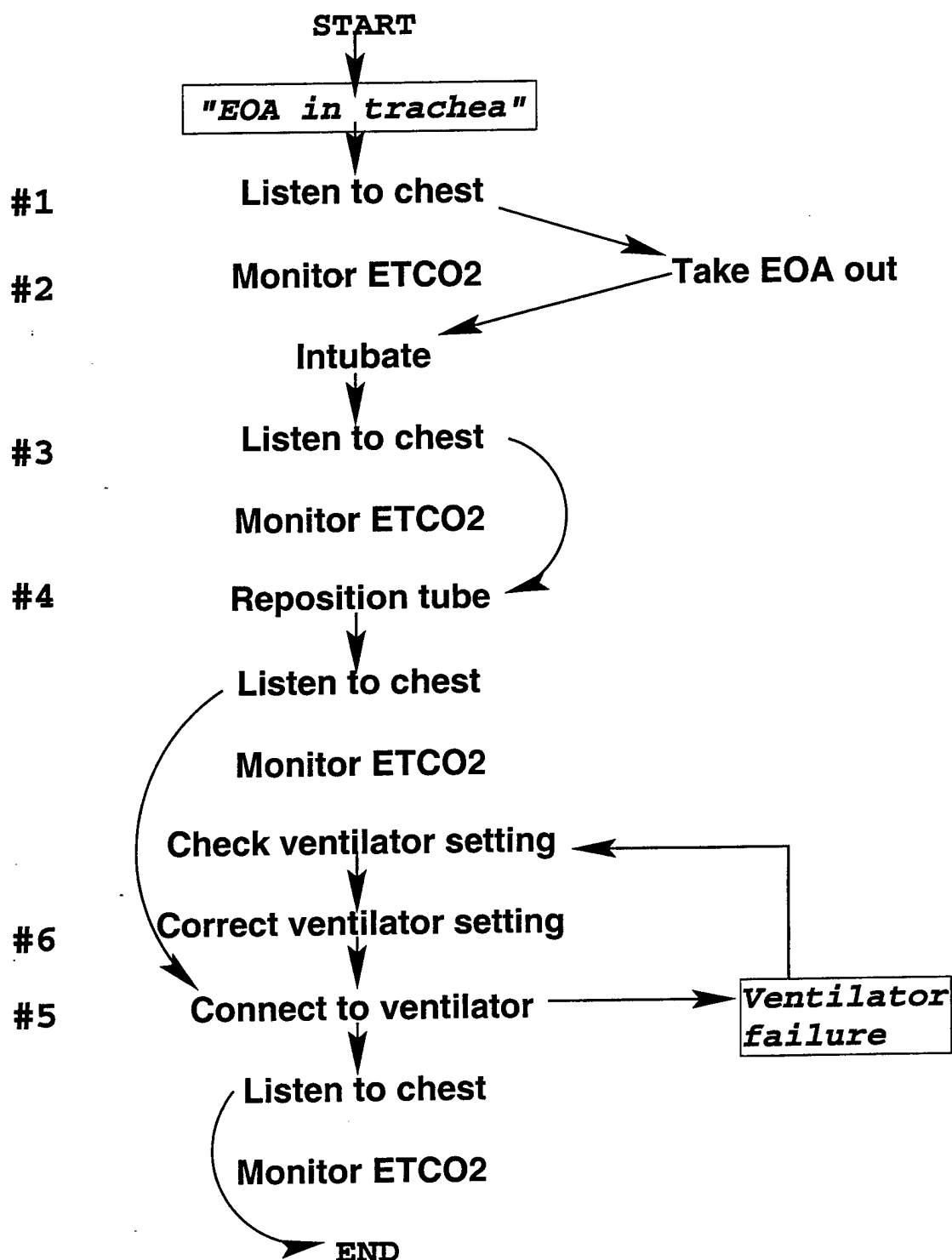


Figure 14.1: Ideal and actual action sequence in the real case. Ideal action sequence is listed in vertical order, whereas real actions are the path shown by arrows. Interesting deviation points from the ideal action sequence are marked by landmarks 1-6.

to the CAE or LORAL simulator. They were trauma anesthesiologists familiar with management of unconscious trauma patients. However, four of the ten participants were unfamiliar with the mechanical ventilator used in the simulation and all the participants were unfamiliar with a particular manufacturer's end-tidal CO_2 (ETCO_2) monitor used in the simulator. They all, however, knew the technique of using ETCO_2 monitoring to detect ventilation and correct placement of the breathing tube in the airway. In addition all participants were familiar with the two simulators. Participants were given material describing the simulators and their functions. Then together, all participants received a verbal explanation of what was planned. They were given a written case summary providing a history and physical exam of the real patient. The real videotape of patient management was next shown and the supervisor whose role they would play was identified. The videotape was stopped before the critical events shown in Figure 14.1 occurred, but the case continued in the simulator with each participant individually managing the case scenario. The sound track of the real video was played as background throughout the continued simulation. Each simulator was assigned three instructor/actors. After the simulation, participants and instructor/actors completed a questionnaire identifying their views on usefulness of simulator in training, research and evaluation of competence. Two hours later, when all participants had completed the simulation the participants were fully debriefed. The entire proceedings including introduction, all simulations and the debriefing were videotaped.

Results

There were ten participants, five performed on each of the two simulators. The various paths taken during the simulated and real event are shown schematically in Figure 14.2.

The evaluation of the participants performance on the simulator was carried out at six major landmarks (see Figure 14.1) in case management

Standard operating procedure in management of the esophageal obturator airway (EOA) recommends leaving it in position until the airway is secured with a conventional cuffed tracheal tube (ET tube). Seven participants removed the EOA without first inserting the ET tube. Four participants made an incorrect diagnosis that the ET tube was in the esophagus (Figure 14.3) after observing the movements of the upper abdomen and examination of the chest. Only two participants used the available ETCO_2 analyzer to distinguish esophageal from tracheal placement of the ET tube.

Nine of ten participants eventually recognized endobronchial intubation from the unilateral movements of the chest and absence of breath sounds. However, one participant confused this with pneumothorax which has similar clinical signs, with the main clinical differentiation being that percussion of the chest is hyperresonant in pneumothorax and dull in endobronchial intubation. Such differentiation is not realistically made in the simulator mannequin (although it is the state of the art). The other participants corrected the endobronchial intubation and one used the tube insertion depth marked on the ET tube to confirm correct depth placement during manual ventilation with a resuscitator bag.

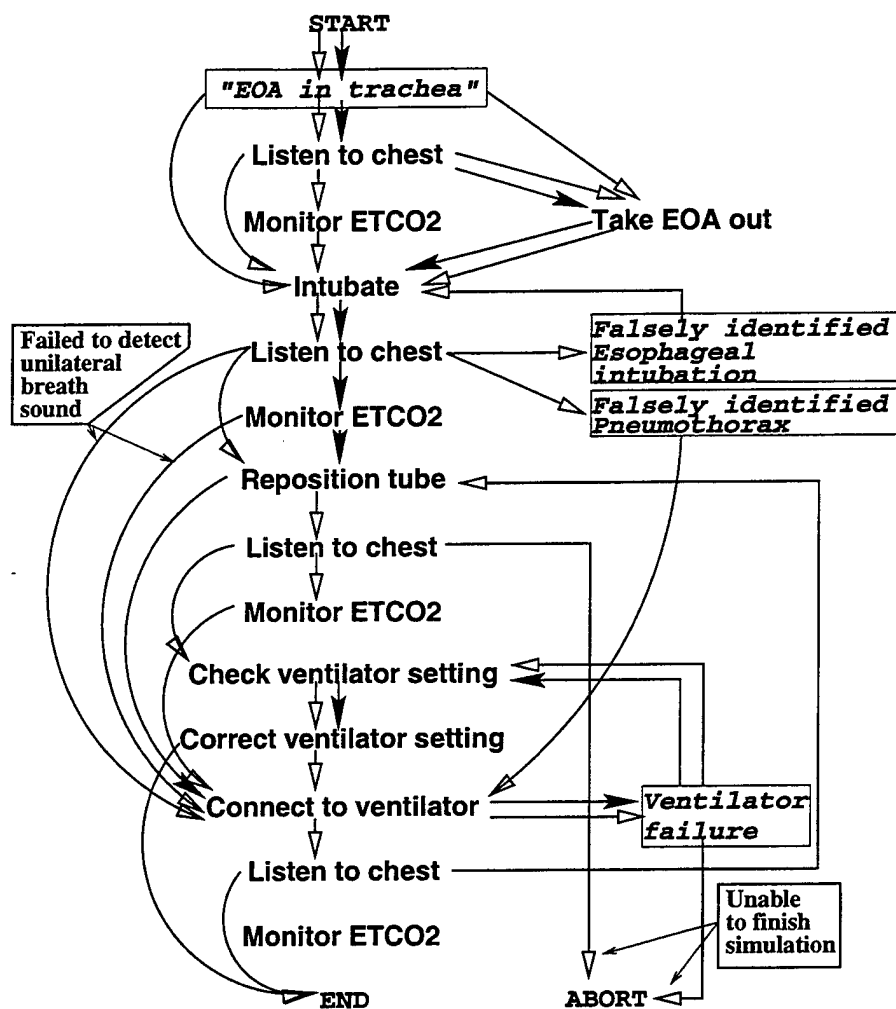


Figure 14.2: Comparison of paths of action sequences taken in real events and in simulated events. Paths with solid arrowheads were taken in the real case; those with outline arrowheads were taken in simulation

	Landmark	Simulator Result
1.	Take EOA out/Leave in	7 out/3 in
2.	Use ETCO ₂ analysis	2 used/8 no
3.	Recognize endobronchial intubation	4 -9
4.	Correct endobronchial intubation	5 -9
5.	Detect failure of ventilator	6
6.	Correct failure of ventilator	6

Table 14.1: Evaluation parameters, and frequency of completion of simulator tasks among ten participants.

Discussion

This experiment indicates that clinical cues (as opposed to monitor cues) used by clinicians change the decision making process. These cues are subtle and the provision of them is limited by the limitations in mannequin's technology. False positive information obtained from examination of the mannequin (e.g. movements of upper abdomen and examination of chest) can change performance dramatically compared to the real case management. Twice as many participants failed initially to diagnose endobronchial intubation as were successful. In the real event cues obtained from clinical examination lead immediately to accurate diagnosis. In the mannequin, movement of the upper abdomen made the diagnosis ambiguous. The results also suggest that clinicians use physical examination (inspection and auscultation particularly) but rarely confirm findings with technology. ETCO₂ monitoring provides clear cut data in ambiguous circumstances of EOA placement, endobronchial intubation and ventilator malfunction but was not often utilized in the simulator, or the real environment, because there was no connector for CO₂ sampling in the manual ventilation circuit. A procedural change in equipment preparation (placing the CO₂ connector in the set-up before cases begin) has eliminated this barrier to ETCO₂ monitoring in the real environment.

The limiting factor is the mannequin realism which provides degraded clinical cues, unlike real patients. We believe this was a major cause of the misdiagnoses made by the experienced trauma anesthesia providers. The results of the current study on simulators show that evaluation of participants performance: a) is altered by unfamiliarity with complex equipment; b) is biased by mannequin realism which limits the availability of subtle cues; and c) allows only certain aspects of the clinician's skills (e.g. task prioritization and therapeutic interventions, but not physical diagnoses) to be tested in a simulator.

14.2 Decision Trees

Many decisions during trauma resuscitation and anesthesia are based on the patient's physiology. Parallel to the efforts in the project reported here, a set of decision trees were developed to articulate the normative decision process in prototypical trauma patient care scenarios. These scenarios include hypotension, hypertension, hypoxemia, hyperthermia, tachycardia, bradycardia, high CO₂, low CO₂, and hypothermia. The decision tree for hypotension is shown in Fig 2.3. For comparison, the decision tree for hypertension is given here in Fig 14.4. These decision trees were the result of multiple consensus building sessions among a group of experienced trauma anesthesiologists.

By utilizing the time-stamped data from patient monitors acquired through VASNET, we could analyze the decisions observed on the videorecordings in relationship with the decision trees developed. We illustrate one such example here, which includes both hypertensive and hypotensive episodes. The patient was in the operating room for an exploratory laparotomy after a car crash. Figure 14.5 shows three decision points. At Point A, the anesthesiologist responded to the low readings of central venous pressure by giving the patient a fluid bolus (500 cc). At Point B, the anesthesiologist gave the patient analgesia and muscle relaxants in responding to high blood pressure readings. At Point

C, since the patient was receiving rapid fluid infusion, the anesthesiologist decided not to intervene but to wait for surgical stimulation (which usually causes a rise in the patient's blood pressure).

Decision points A and B are covered by the decision trees developed (Figs 2.3 and 14.4, respectively). However, the response by the anesthesiologist at Point C was not covered in the hypotension decision tree. The current example illustrates that the normative decision trees could be used to explain and measure decision making performance, although they are not exhaustive and able to explain all decisions observed.

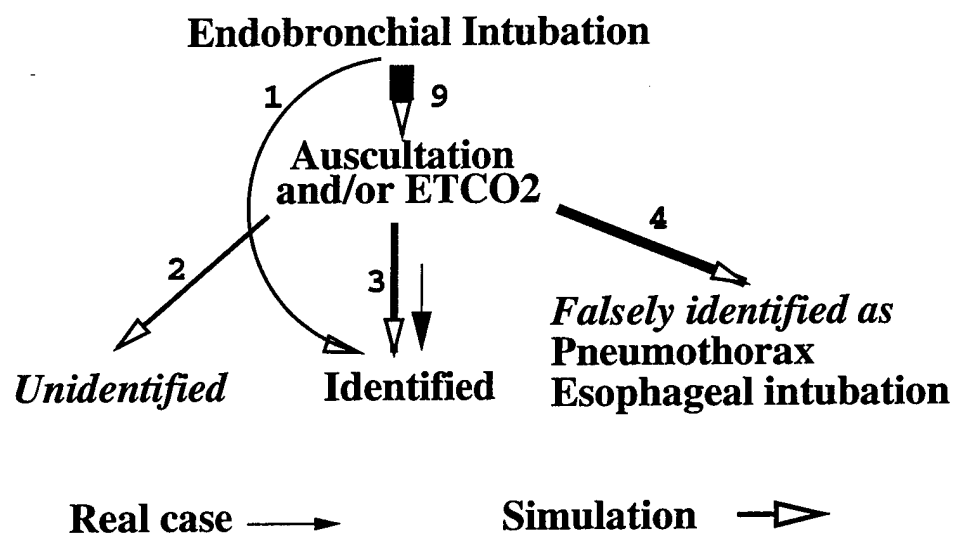


Figure 14.3: Differential diagnoses made by simulator participants after endobronchial intubation (EI).

Hypertension: Systolic BP >160, Diastolic BP >90 or 40% increase over norms.

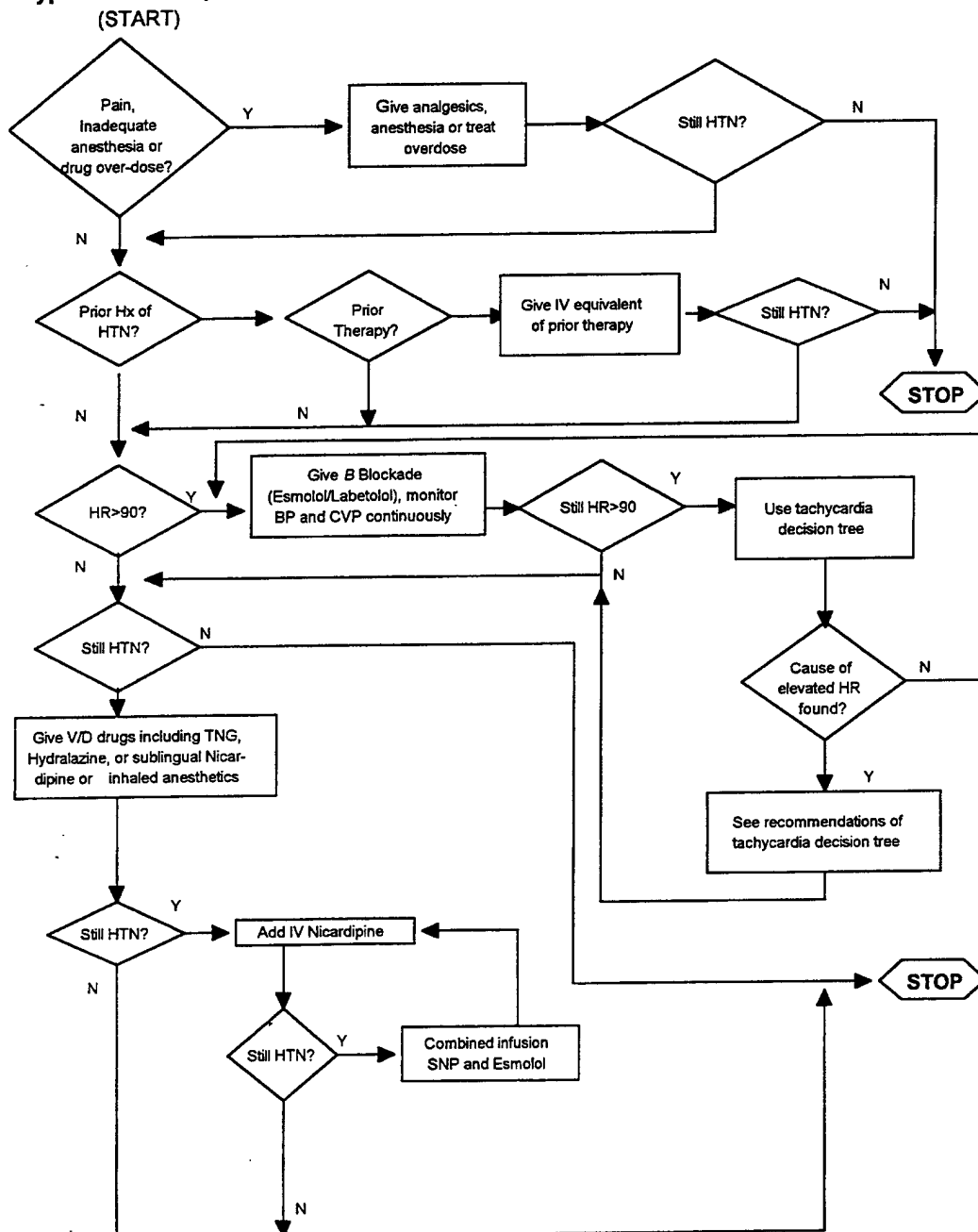


Figure 14.4: Hypertension decision tree.

Blood Pressure (mmHg) & Heart Rate (beat/min)

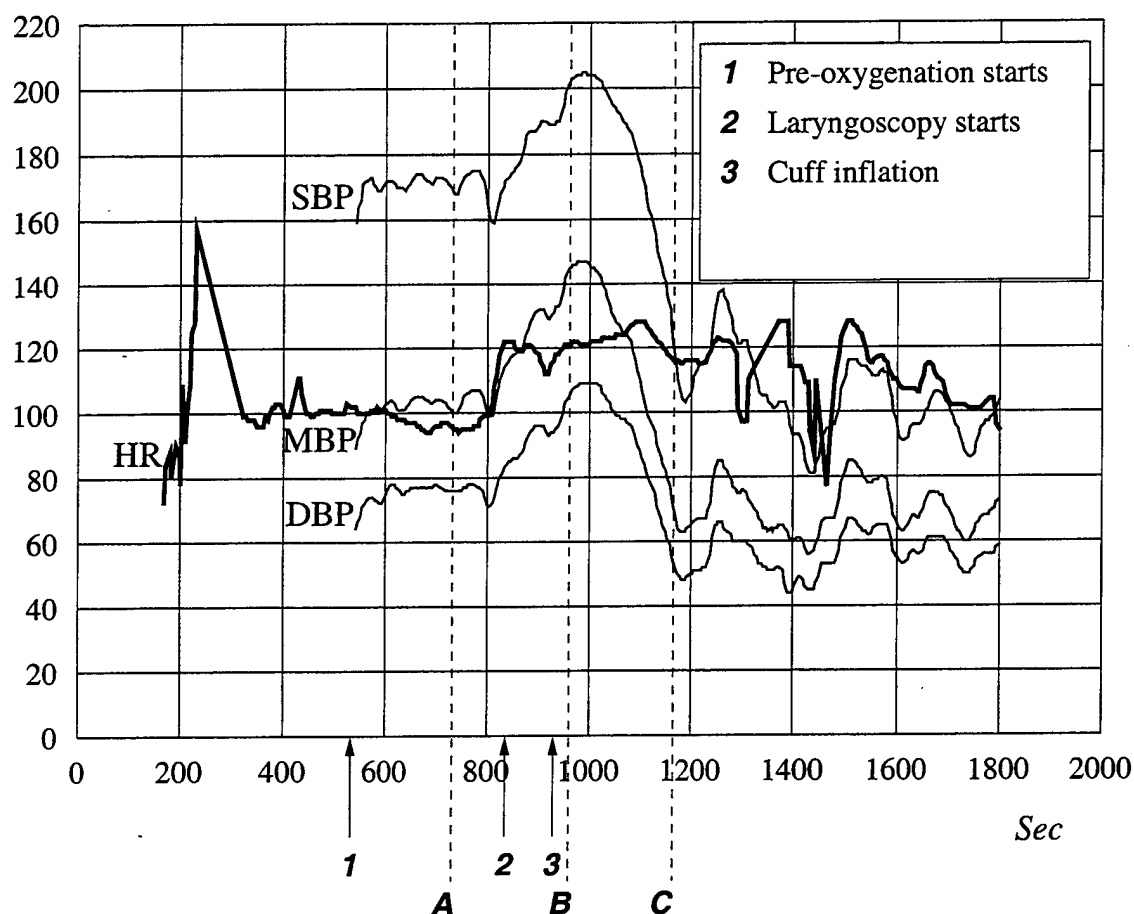


Figure 14.5: Patient vital signs and decisionmaking: an example of fluid management. SBP: systolic blood pressure; MBP: mean blood pressure; DBP: diastolic blood pressure. A: patient's central venous pressure reading (not shown in the figure) was 3 cm H₂O (a very low reading, indicating low circulation volume). Attending anesthesia care provider requested rapid fluid infusion to elevate circulation volume. B: patient's blood pressure was extremely high, possibly due to the laryngoscopy. Attending anesthesia care provider administered analgesic drugs to reduce blood pressure (see Decision Tree for hypertension in Figure 14.4). C: patient's blood pressure was extremely low (see Decision Tree for hypotension Figure 2.3).

Chapter 15

Future Applications

The efforts of the present project generated materials and methodologies that can be used in a number of applications. Several examples of future application are described here.

15.1 Telemedicine

Telecommunication advances enable remotely located individuals to collaborate on problem-solving with expertise unavailable locally. Increasingly telecommunication systems have become an integral part of many professions. Interesting and challenging research issues arise in the use of telecommunication systems in decision making and problem solving, many of which have been discussed in the context of distributed decision making and computer supported cooperative work (Kiesler *et al.*, 1984; National Research Council, 1990; Rasmussen *et al.*, 1991; U.S. Congress, Office of Technology Assessment, 1995). Little empirical data have been reported on how people can assess dynamically changing situations and problems through telecommunication links. Therefore little empirical basis exists to guide the design of telecommunication systems in support of distributed decision-making in this regard.

The videorecordings made during the current project provide multimedia data which can be used in experimentation on the value of various information to be transmitted in distributed decision making and in development of principles for designing telemedicine systems. For example, recently we used the audio-video data of real patient resuscitation in a NASA-funded project examining remote Diagnosis for Trauma Patient Resuscitation. This project addresses the cognitive demands of distributed medical decision making as it pertains to the treatment of acute trauma patients. We planned to use this database: 1) to investigate what information a remote medical decision-maker requires to supervise management of emergencies and how effective remote management is at producing appropriate and timely diagnoses and intervention; 2) it is also not known how different types of medical SME's (surgeons, anesthesiologists, nurses) function as independent remote decision-makers; 3) how the response of the on-site trauma patient managers affects the remote decision-maker is also uncertain; and 4) determine whether decision-making aids could improve the efficacy of remote decision-making.

In the first phase of the project, six anesthesiologists, all experienced in trauma patient care, attempted a remote diagnosis task, in which the subjects were presented with audio-video case segments of trauma patient resuscitation and were requested to report their knowledge of patient and resuscitation status. The major findings of the data analysis include (1) critical visual and auditory cues were often missed by the subjects (2) the subjects seemed to be overloaded by multiple-activity threads contained in the audio-video scene (3) patient history information was critical for the subjects to understand audio-video scenes (4) secondary cues (such as facial expressions visible from the video scenes) were used to determine patient resuscitation status (Xiao & Mackenzie, 1996). In the second phase of the project (Xiao *et al.*, 1997), 4 attending trauma surgeons and 4 experience trauma nurses attempted the same remote diagnosis task. Combined with the data collected in the first phase, the three groups of experts (surgeons, nurses, and anesthesiologists) differed in their abilities to detect critical cues and offer diagnostic suggestions. It appears that experts were bounded by their own regular roles in a resuscitative team. For example, the anesthesiologists were able to understand airway management related patient and resuscitation status better than the surgeon and nurse subjects. The findings suggest that to provide consultation of dynamic, multidisciplinary team oriented activities, either an assembly of teleconsultants or special training are needed to provide effective consultation.

15.2 Evaluation of Performance and Procedures

A problem with establishing performance and decision-making during a life threatening event is that such events are rare and recall is often incomplete. Video taping of trauma patient resuscitation enables life threatening situations to be documented and allows events to be objectively recorded and subsequently analyzed. Certain systems errors (such as lack of training, workplace layout, and work process design) are difficult to identify with current documentation and analysis methods (Mackenzie *et al.*, 1996a).

For example, in our analysis of videotaped airway management resulted in the identification of performance flaws in the use of end-tidal CO₂ analysis, which is the gold standard in determining the correct placement of endotracheal tubes. Further, it was determined that such performance flaws were frequently induced by the lack of means for the anesthesia care providers to easily attach CO₂ analyzers into the ventilation circuit when the patient was ventilated through manual ventilation resuscitator bags. A solution was to insert a connector (which costed a few cents) in the ventilation circuit to make the use of CO₂ analyzer possible. Since that time, no undetected esophageal intubation has occurred. As another example, the task of auscultation (listening with a stethoscope) after the placement of the endo-tracheal tube was often delegated and such delegation was found to be a cause of errors in confirmation of the tube position. A recommendation was made to modify the work process, to specify that the person performing intubation should listen to the patient's chest, thus avoiding delegation and making the task less error-prone.

Chapter 16

Summary

The findings of this exploratory research effort include substantive evidence that trauma patient resuscitation and anesthesia are high stress domains. A dynamic evaluation of perceived stress obtained by analysis of videotapes for a single task (tracheal intubation) showed increased stress ratings when the task became urgent and, the ratings showed nearly parallel increases and decreases in temporal profiles with different task urgencies. Personal involvement increased the emphasis on workload compared to ratings by non-involved neutral raters'. Principal component analysis of 7 measured subjective ratings of stress showed a high commonality among items. The first two principal components account for more than 75% of the variance suggesting stress was rated on a single dimension, although methodological limitations may have confounded these data.

The domain of trauma patient resuscitation was found to have a higher than normal and under-reported rate of non-optimal performance. Video analysis revealed decision-making errors, a sentinel critical event, and team communication and coordination failures undetected by self-reporting systems. Results of our analysis for causes of non-optimal performance include failures to follow standard operating procedures, poor communication among team members, and system failures which hindered performance and promoted errors. An algorithm that includes both a task sequence and a communication protocol was recommended to overcome non-optimal performances. A simple change in the configuration and placement of equipment in the patient resuscitation area rectified the system failures and has prevented a repeat of the sentinel event during the last 4 years.

Analysis of videotaping of high stress tasks highlighted the dynamic and uncertain nature of such a complex work domain. Fixation errors occurred as a result of unreliable signals from patient monitoring devices and delays in feedback of information. In complex, uncertain domains multiple confirmatory signals are used. Fixation errors occur when redundant information substitutes for unreliable signals creating a false sense of system stability.

Team performance under stress was examined by evaluating team coordination and determining when coordination breakdowns occurred. A study was conducted to contrast the same high stress emergency medical procedure (tracheal intubation) under two circumstances differentiated by task urgency. The findings revealed that, tasks performed in high urgency situations were carried out with less information on patients whose

condition was more critical than occurred with tasks performed in low urgency situations. The task of tracheal intubation was more difficult in high task urgency situations, but was completed at a faster pace. Components of task complexity occurring in high urgency situations included multiple concurrent tasks, uncertainty, changing plans, compressed procedures, and high workload. Procedures carried out sequentially in low urgency situations may have to be performed concurrently when task urgency is high.

Team coordination breakdowns occurred in four types of situations: 1) when there was pressure to seek alternative solutions or there were conflicting plans, 2) when an unexpected non-routine procedure was initiated or there was inadequate support in crisis situations, 3) when there was diffusion of responsibility and a lack of task delegation, and 4) when there was inadequate verbalization of problems. Team coordination occurs in most situations with minimum explicit verbal communications. When team coordination broke down, there was often a lack of explicit communication. Several forms of non-communication task coordination activities were noted including: following protocols, following the leader, anticipation, and activity monitoring.

Four strategies may improve team coordination in complex environments including use of established work procedures; second, extensive on-job training with anticipatory helping of others on the team without explicit communication. Thirdly, caregivers should have continuous visual and auditory contact. Fourthly, workspace design can promote team coordination by reducing the impact of task complexity.

The products of this exploratory project include:

- A turn-key operated audio-video data acquisition system (VASNET) network to gather human factors and ergonomic data in a dynamic high stress real workplace.
- A video analysis tool (VINA) that integrates multiple data sources in a relational database with audio video material by means of a machine-readable time code. Coding of video was simplified and changed from a time-consuming 200 or more: 1 ratio (coding time: video run time) to 20:1 or less. In some instances where a specific structure for analysis was pre-determined, trained graduate students could perform on-line coding of events (1:1).
- A framework for coding and analysis of verbal communications.
- A model for predicting stress from stressors
- A method to measure dynamic stress was validated during this research.
- A library of video tapes was collected that include a spectrum of different levels of stress task urgency and outcome. Supporting documentation includes subjective stress ratings, audio commentary by participant and non-participant care providers, case discharge summaries, anesthetic and surgical records, laboratory data, and in about 35 cases, communication analyses. In addition, a 32-item questionnaire was completed by the care providers immediately after the videotaped management was completed.
- A data extraction framework, performance metrics, a task analysis and a task communication algorithm for tracheal intubation were developed.
- A process to re-engineer the workplace was developed using video data, link analyses, workspace appropriateness, and item importance.
- A systematic analysis of auditory alarms in the workplace was conducted.
- An analysis framework of team coordination and its breakdowns was described.

- A decision error analysis methodology which identifies system errors was developed.

The data collected are under ongoing and future analysis in various aspects of decisionmaking under stress and performance in real environments.

16.1 Implication for Future Research on Team Performance and Stress

Training The findings from the current studies suggest three strategies for training: (1) Increasing team coordination (2) Standardizing verbal communication protocols (3) Development of clinical pathways and protocols.

Although implicit coordination is used in the overwhelming majority of situations, under stress when plans and routine are disrupted by a truly unexpected event, team dyscoordination occurs because explicit coordination is then required.

Dynamic stress The current project showed that it is feasible to measure stress using both subjective as well as physiological measures in real work environments. The data collected demonstrates that subjective measures can reflect the dynamic changes during the course of performing a stressful task. For future applications of stress measurement, the following implications are suggested here.

First, there is a tendency for subjective measurement of stress to follow one dimension. Although this findings needs to be verified, two possible actions are recommended. Either one should separately measure one dimension at a time (instead of measuring multiple at the same time), or simplify the measurement scale and focus on one single dimension. Secondly, physiological measures during the performance of tasks have to be fine-grained in terms of temporal resolution. Changes in stress level, as demonstrated in the current project, are high enough so that minute-to-minute measures of subjects' physiological measures (such as heart rates or blood pressures) are necessary to reflect changes in stress.

Performance and stress The current project established general correlations between performance and stress, although, as previous studies have shown, the relationship between performance and stress is not clear. An inverted-U curve is still a prevailing working hypothesis between performance and stress (Yerkes & Dodson, 1908; Janis & Mann, 1977).

16.2 Future application of the results and products of this research

The library of videotapes and supporting interpretation is a valuable resource that can be used as a control population for a variety of human factors and medical research projects.

The videotapes will be used to investigate what information a remote medical decision-maker requires to supervise management of emergencies. The audio-videotapes will also be used to examine the added value of video over audio (a commentary will be provided without images), and the benefit to decision-making of continuous vital signs data compared to intermittent verbalizations.

Furthermore, the audio videotapes will be used as stimulus material to examine how effective remote decision-makers are at identifying appropriate and timely diagnoses and interventions. Lastly, the audio videotapes will be used to test how different types of medical subject matter experts (surgeons, anesthesiologists, and nurses) function as independent remote decision-makers. The audio videotape library may be used to test whether decision-making aids can improve performance of remote decision-makers. Training techniques may be developed as a result of the task analyses that develop established work procedures. Primary underlying team coordination breakdowns may be used to identify team training strategies. Standardized verbal communication protocols developed from communication analysis may improve individual and remote decision-making performance.

16.3 Conclusions

The report characterizes the nature of errors using the task model of tracheal intubation - a high stress task. Using a framework established by task analysis, the report shows how communication failures, omission of standard operating procedures, and systems failures contributed to errors.

Performance of the care providers was quantitated by temporal measurement, conformity to a expert developed process model, and inclusion of high priority tasks in urgent and stressful situations. Subjective stress scores show that dynamic ratings can be used to identify differences in task urgency, and perceived stress appears to be uni-dimensional in character.

Explicit communications occurred less frequently than anticipated, but were found to be omitted in several cases in which non-optimal care or errors occurred. Analysis of team coordination strategies identified non-verbal techniques used in dynamic stressful domains such as trauma patient resuscitation.

Several cognitive and decision-making models were hypothesized and described in this report. Recommendations that may be used in training programs were described, including task/communication protocols and techniques to avoid team coordination failures.

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Appendix I: Questionnaires

Four data collection forms were designed to assist the analysis of videotapes and they are included in this report:

- Post Trauma Questionnaire (PTQ)
- Intubation Analysis Questionnaire (IA)
- Stressor Collection Form
- Recall Questionnaire

ANESTHESIOLOGIST/CRNA**POST TRAUMA RESUSCITATION/POST ANESTHESIA QUESTIONNAIRE**

PLEASE COMPLETE THIS FORM AS SOON AS POSSIBLE AFTER FINISHING THE CASE AND STORE WITH VIDEO TAPE(S) IN LOCKED CABINET. COMPLETE THIS FORM FOR CASES VIDEO TAPED IN A.A. OR O.R. IF A GIVEN PATIENT WAS VIDEO TAPED IN BOTH THE A.A. AND O.R., COMPLETE SEPARATE FORMS FOR EACH.

1. Last 4 digits of your SSN #: _____ 2. Admission time & Date: _____ 3. MIEMSS Patient #: _____

Patient

4. Location of Video (Circle as appropriate): A.A. O.R. 5. Bay # _____

Please score this videotaped patient by: 6. AIS _____ 7. GCS _____ 8. ASA _____ 9. TAG _____
(See VCR for abbreviated score systems) (0 = no injury) (15 = norm) (I-V) (I-IV)

Fatigue (Enter time estimates with respect to the start time of the video taped case)

10. How many hours sleep did you have the last time you slept? _____ Hours 11. How long since you last slept? _____ Hours

11A. Stanford Sleepiness Scale: Choose the one of the seven statements below that best describes how you are feeling:

At case	At most profound		Comments on
start:	level of fatigue		Fatigue:
during case:			

_____	_____	Feeling active and vital; alert; wide awake.	_____
_____	_____	Functioning at a high level, but not at peak; able to concentrate.	_____
_____	_____	Relaxed; awake, responsive, but not at full alertness.	_____
_____	_____	A little foggy; let down; not at peak.	_____
_____	_____	Foggy; slowed down; beginning to lose interest in remaining awake.	_____
_____	_____	Sleepy; woozy; prefer to be lying down; fighting sleep.	_____
_____	_____	Almost in reverie; sleep onset soon; losing struggle to remain awake.	_____

12. What hours (e.g., between the 1st and 12th hour) of your present on-call did the videotape include? Hours _____ to _____

13. When were you last on call (circle as appropriate)? <1 1-2 2-7 >7 days

14. How many hours of the present on-call period have you been actively involved in patient care? _____ Hours

Experience

15. Approximately how many similar cases have you managed (to the one just videotaped) in your career. Number = _____

16. How long ago was the last similar case (circle as appropriate)? 0-3 mos 3-6 mos 6 mos - 1 yr 1 yr or more ago

17. How many times have you worked with this team leader/surgeon (circle as appropriate)? 0 1-3 4-9 10-30 >30

18. How long since you completed a case with this team leader/surgeon (circle as appropriate)? <24 hrs <1 wk 1 wk-1 mo >1 mo

Ratings/Comments

Please complete the following scales of your perception of the present resuscitation and anesthesia. When answering scales below please consider the sum total of all your past experience. The mid-point would be typical or average for all cases you have managed, not just patients of this type.

Mark scale with a vertical line as in this example: → →

Typical

Comments

19. Exhausted _____ Not at all
Fatigue (by end of case)

PLEASE ALSO COMPLETE BACK OF FORM →→→→

Figure I.1: Post Trauma Questionnaire (PTQ)

	Typical	Comments
20. Least	<div style="display: flex; justify-content: space-between;"> Most </div> <p style="text-align: center;">Your Overall Stress Level (i.e. overall stressfulness of this case)</p>	
21. Worst	<div style="display: flex; justify-content: space-between;"> Best </div> <p style="text-align: center;">Effectiveness of Your Interaction With Surgeon(s)</p>	
22. Worst	<div style="display: flex; justify-content: space-between;"> Best </div> <p style="text-align: center;">Effectiveness of Your Interaction With CRNA(s) & Anesthesiologist(s)</p>	
23. Worst	<div style="display: flex; justify-content: space-between;"> Best </div> <p style="text-align: center;">Effectiveness of Your Interaction With A.A. or O.R. Nurse(s)</p>	
24. Worst	<div style="display: flex; justify-content: space-between;"> Best </div> <p style="text-align: center;">Team Work During Resuscitation/O.R. (Consider the whole trauma team)</p>	
25. Worst	<div style="display: flex; justify-content: space-between;"> Best </div> <p style="text-align: center;">Your Own Performance</p>	
26. Least	<div style="display: flex; justify-content: space-between;"> Most </div> <p style="text-align: center;">Difficulty of Case (Consider both the pt's condition and events that occurred during treatment)</p>	
<p>27. Were there any specific stressful events? Y/N If yes, identify.</p>		
<p>28. Did you make any misjudgments in management? Y/N If yes, identify.</p>		
<p>29. In retrospect, if you had the identical patient again would you manage the same way? Y/N If no, please identify what you would do differently.</p>		
<p>30. Consider the following to be a time-line spanning the case just video-taped. The time-line is divided into twelve equal segments. Please indicate the units (as applied to the total duration of this case) and block off periods of time that were particularly stressful. Briefly note what was happening during these periods that made each somewhat stressful.</p>		
<div style="display: flex; align-items: center;"> <div style="text-align: right;">Time</div> <div style="flex-grow: 1; border-bottom: 1px solid black; position: relative;"> <div style="position: absolute; left: 0; top: -5px;">in</div> <div style="position: absolute; right: 0; top: -5px;">out</div> <div style="position: absolute; left: 0; right: 0; top: 5px; height: 1px; background: linear-gradient(to right, black 1%, black 1%, white 1%, white 1%, black 1%, black 1%, white 1%, white 1%, black 1%, black 1%, white 1%, white 1%);"></div> </div> <div style="text-align: left;">Time</div> </div>		
<p>THANK YOU FOR PARTICIPATING.</p>		
<p>PTQS.wp5 Revised 01/31/94 V2.2</p>		

Figure I.1. Post Trauma Questionnaire (PTQ) (continued - p.2 of 2).

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Intubation Analysis

The object of the intubation sequence analysis is to gather detailed information about emergency and elective tracheal intubation. We will construct a database using the enclosed questionnaire that we will complete for each intubation case (we have about 60-70 such cases).

The database will include:

- 1) Clinical Information (indication for intubation, monitors used, difficulties occurring, drugs used)
- 2) Rules for Intubation (practices that are considered usual for "pre", "during", and "after" phases of intubation management.)
- 3) Assessment of Psychomotor Skills (and factors that impair these skills and some quantification of how much they delayed intubation.)
- 4) Decision-making/cognitive skills/Knowledge based skills (we want to tie this in with:)
 - a) our subjective ratings of stressors
 - b) the decision trees
- 5) Precise timing of major events in the intubation sequence (among different cases)
- 6) Psychological aspects of decision-making (Communication / preparation / decision tree issues.)
- 7) Data (to enable a survey of practices and identify subgroups for comparison of decision-making under stress.)

We will start by reviewing the anesthesia record and case summary and OCS summary files. Then start the video tape about 10 min before intubation was thought to occur. Watch the video making mental notes of your overall impression. Complete the intubation sequence analysis questionnaire. You will certainly have to review the 10 min before, during and after intubation sequence several times to complete the form. You must have OCS Tools running to record times.

STATUS:

AIS _____ GCS _____ ASA _____ TAG _____

Check all applicable categories:

- | | |
|----------------------------|-----------------------------------|
| 1. Teaching tape _____ | 4. Equipment malfunction _____ |
| 2. Ergonomic issue _____ | 5. Man/machine problem (eg. _____ |
| 3. Critical incident _____ | monitor/ventilator) _____ |
| 6. Error detected _____ | |

Figure I.2: Intubation Analysis Questionnaire (IA)

2

Case # _____ Reviewed by: _____ Date: _____

O.C.S. START TIME FOR INTUBATION SEQUENCE: _____:_____:_____
(When anesthesiologist mask is placed on for preoxygenation)I) Indication for Intubation (Check all that apply)

- A) _____ Airway obstruction that cannot be simply relieved
 B) _____ Hypoxemia *
 1) _____ PaO₂ <80 mm Hg (SaO₂ <95) on mask O₂ or
 2) _____ PaO₂ <60 mm Hg (SaO₂ <90) on air
 C) _____ In shock *
 1) _____ Systolic BP <80 mm Hg
 D) _____ Head injury
 E) _____ Unconsciousness
 F) _____ Lung contusion suspected
 G) _____ Surgery highly likely
 1) _____ Obvious Fx/bleeding sites, or
 2) _____ Elective case
 H) _____ Enable placement of monitors / investigations /
 peritoneal lavage, etc. in combative patient:
 AA Protocol implementation necessitates
 intubation. (Combative/patient: lack of
 cooperation appears to be the reason for
 intubation; there should be NONE of the other
 indications present.)
 J) _____ * If not meeting these criteria please identify
 1) _____ PaO₂ _____
 2) _____ SBP _____

II) Monitors (Can be seen or heard.)A) In place at time of intubation (circle below):

- 1) SaO₂ 2) ETCO₂ 3) BP 4) ECG 5) CVP 6) PA
 7) Temp 8) Nerve Stimulator 9) Other

B) During and immediately after intubation (circle below):

- 1) SaO₂ 2) ETCO₂ 3) BP 4) ECG 5) CVP 6) PA
 7) Temp 8) Nerve Stimulator 9) Other

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.2 of 11).

3

III) Intubation Drugs (Drugs used - circle drug used and write dose.
State if dose not recorded.)

A) Induction

- 1) Pentothal _____
- 2) Ketamine _____
- 3) Etomidate _____
- 4) Propofol _____
- 5) Other (Identify) _____

B) Muscle Relaxant

- 1) Succinylcholine _____
- 2) Pancuronium _____
- 3) Vecuronium _____
- 4) Atracurium _____
- 5) Curare _____
- 6) Other (Identify) _____

IV) Intubation Route (from record - circle below):

A)

- 1) ORAL 2) NASAL 3) CRICOTHYROID 4) TRACHE

B) Cervical Collar Used? Y / N

V) Intubation Assist

- A) Gum Elastic Bougie Y / N
- B) Stylet Used Y / N
- C) Laryngeal Mask Y / N
- D) Other _____ Y / N (Identify)

VI) Status

A) Identify Whether: (Circle)

- 1) Elective
- 2) Semi-Emergency (not time critical but urgent)
- 3) Real-Emergency (Precipitous requirement for Intubation)

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.3 of 11).

4

B) Identify location: (Circle)

- 1) OR 2) AA

C) Instrumentation:

1) Tube size Recorded _____

2) Number of Attempts _____

3) Difficulty: (Circle)

- a) Not Difficult b) Normal c) Very Difficult

4) Blade Size _____

D) Was there a critical Incident?

(vomit / esoph intubation / hypotension etc...)

1) Y / N (Circle)

(If YES, explain) _____

VII) Rules of Intubation: State whether followed or not (circle)

- | | | | |
|---------------|--|---|---|
| | 1) Pre-oxygenate. | Y | N |
| | 2) Head positioned before intubation | Y | N |
| | 3) In-line stabilization used | Y | N |
| | 4) Suction ready? | Y | N |
| A) <u>Pre</u> | 5) SaO ₂ monitored pre-induction? | Y | N |
| | 6) ETCO ₂ monitored pre-induction? | Y | N |
| | 7) BP monitored pre-induction. | Y | N |
| | 8) HR monitored pre-induction. | Y | N |
| | 9) Cricoid pressure indicated. | Y | N |
| | 10) Cricoid pressure correctly applied. | Y | N |
| | 11) Cricoid pressure maintained until cuff up and ventilated. | Y | N |
| | 12) IV running pre-intubation. | Y | N |
| | 13) Drugs given satisfactorily? | Y | N |
| | 14) Did anesthesiologist and/or CRNA have stethoscope? | Y | N |
| | 15) Was this sequence exactly followed: preox, monitors, cricoid, drugs. | Y | N |

-
- | | | | |
|--|---|---|---|
| | 1) Intubation equipment ready? | Y | N |
| | 2) Check neuromuscular block before DL? | Y | N |

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.4 of 11).

5

- B) During
- | | | |
|---|---|---|
| 3) If 3 attempts fail is pt re-oxygenated? | Y | N |
| 4) Is cuff inflated to just seal? | Y | N |
| 5) Is tube insertion distance checked? | Y | N |
| 6) Is left and right side of chest auscultated by anesthesiologist, CRNA, or other? | Y | N |
| 7) Is upper abdomen auscultated by anesthesiologist, CRNA, or other? | Y | N |
| 8) If cuff not inflated to just seal, is cuff inflation re-checked? | Y | N |
| 9) Is tube taped or tied in position? | Y | N |
| 10) Was timeliness of intubation appropriate? | Y | N |

-
- C) After
- | | | |
|--|---|---|
| 1) Is the chest listened to after connected to ventilator? | Y | N |
| 2) Is ETCO ₂ monitored within 2 min after intubation? | Y | N |
| 3) Is ETCO ₂ monitored within 4 min after intubation? | Y | N |
| 4) Is NM block checked before giving non-depol block? | Y | N |

VIII) Logistics of Intubation

- A) Tasks
- | | | |
|--|---|---|
| 1) Was there appropriate assistance? | Y | N |
| 2) Was it an efficient intubation? | Y | N |
| 3) Did anesthesiologist specifically delegate tasks? | Y | N |

IX) Psychomotor Skills

A) During Intubation Sequence (mark the analog scale)

- | | |
|---------------------------|------------------|
| 1) Mask Ventilation | Best _____ Worst |
| 2) Laryngoscopy | Best _____ Worst |
| 3) Equipment Handling | Best _____ Worst |
| 4) Intubation | Best _____ Worst |
| 5) Post intubation checks | Best _____ Worst |

B) Overall score Psychomotor Skills (circle score)

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.5 of 11).

6

- 1) 5 Very smooth, rapid, no hitches
 4 Smooth, average speed, no hitches
 3 Average smoothness, slower than average, minor hitches
 2 3 attempts or more, takes longer, equipment failure
 1 Multiple attempts, major problems, very slow

- C) What were the major psychomotor factors that impaired performance when a score of 1, 2, 3, or 4 (from above) was obtained?
 (List; estimate time delay for successful intubation.)

	MIN	SEC
1) _____	00:_____:	_____.00
2) _____	00:_____:	_____.00
3) _____	00:_____:	_____.00

X) Decision-Making/Cognitive Skills during Intubation Sequence

- A) Were there errors in decision-making? Y N
 If yes, identify: _____
- B) Were drugs used appropriate? Y N
 If no, identify: _____
- C) Were drug doses appropriate? Y N
 If no, identify: _____
- D) Was intubation decision approached appropriately? Y N
 If no, identify: _____
- E) Was equipment preparation appropriate? Y N
 If no, identify: (suggest how it impaired performance) _____
- F) Were there contingencies present, that may have pointed the anesthesiologist down different branches of the emergency tracheal intubation decision tree? Y N
 If yes, state contingencies: _____
- G) Was patient monitoring appropriate before induction? Y N
 If no, why: _____
- H) What stressors were present in higher than usual levels or levels that would impair your performance if you were doing the intubation (please check)

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.6 of 11).

7

- 1) _____ Adverse non-anesthesia team interactions
- 2) _____ Adverse anesthesia team interactions
- 3) _____ Noise
- 4) _____ Time pressure
- 5) _____ Task workload
- 6) _____ Uncertainty
- 7) _____ Overall stress levels
- 8) _____ Other stressors (list) _____

XI) Timing of events (Please use: OCS Tools time code/Computer Time)
(If the events are not carried out state NOT DONE)

A) Before Intubation:

- 1) ____:____:____.____ Start time of Pre-oxygenation using anesthesia mask? (do not state time when O₂ given by nasal tube O₂ tent or non-rebreather O₂ mask).
- 2) Y / N Was O₂ being given by other means before anesthesia mask is on?
- 3) ____:____:____.____ Time for positioning of head and neck for intubation?
- 4) ____:____:____.____ Start time(s) for cricoid pressure?
____:____:____.____ , ____:____:____.____
- 5) ____:____:____.____ Stop time(s) for cricoid pressure?
____:____:____.____ , ____:____:____.____
- 6) _____ Number of times cricoid pressure applied?
- 7) ____:____:____.____ Start time of IV induction agent?
- 8) ____:____:____.____ Start time of muscle relaxant?

B) During Intubation:

- 1) ____:____:____.____ Start Time(s) for each suctioning of
____:____:____.____ the airway?

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.7 of 11).

8

____:____:____.____ / ____:____:____.____

2) _____ Number of times suction catheter put in and out of mouth?

3) ____:____:____.____ Start Time(s) for each insertion of laryngoscopy?
____:____:____.____
____:____:____.____

4) ____:____:____.____ Stop Time(s) for each insertion of laryngoscopy?
____:____:____.____
____:____:____.____

5) _____ Number of times laryngoscope put in and out of mouth before successful laryngoscopy?

6) ____:____:____.____ Start Time(s) tracheal tube inserted in mouth / into nose?
____:____:____.____
____:____:____.____ / ____:____:____.____

7) _____ Number of times tube put in and out of mouth before successful intubation?

8) ____:____:____.____ Start time for cuff inflation?

C) After Intubation:

1) ____:____:____.____ Time manual ventilation recommences after intubation?

2) (Check) 1st ventilation mode after intubation.
a) _____ Resuscitator bag
b) _____ Anesthesia circuit
c) _____ Mechanical ventilator (without manual vent.)

3) ____:____:____.____ Start Time for listening over right chest?

4) ____:____:____.____ Start Time for listening over left chest?

5) ____:____:____.____ Start Time for listen over upper abdomen?

6) ____:____:____.____ Start Time when ventilator was

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.8 of 11).

9

connected?

- 6.5) ____:____:____.____ Time when mechanical ventilator ventilates patient
- 7) ____:____:____.____ Start Time for listening over chest to confirm ventilator ventilating?
- 8) ____:____:____.____ Start Time when anesthesiologist and CRNA first look for CO₂ signal?
- 9) ____:____:____.____ Finish Time when tube was taped?
- 10) ____:____:____.____ Start Time when tube cuff inflation / overinflation checked?
- 11) ____:____:____.____ Start Time when tube depth is checked?

XII) Cognitive Skills in association with intubation

A) Laryngoscopy Performed by: (circle)

- 1) MD Attending 2) MD Fellow 3) CRNA 4) Non-anesthesia
5) _____ personnel

B) Difficulty of Intubation?

Easy _____ Most Difficult

C) Timeliness of the intubation in relation to the clinical situation?

Delayed _____ Hasty

D) Was intubation necessary?

Necessary _____ Not Necessary

E) Did the anesthesiologist consider all the relevant issues / complications associated with intubation?

All issues considered _____ Lack of Planning

F) Was preparation for intubation adequate?

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.9 of 11).

10

very adequate _____ Inadequate

G) Did the anesthesiologist use all available history / clinical exam / lab data?

Used data _____ Data clearly
efficiently _____ not used

H) How often did the anesthesia team look at patient monitors?

Frequently _____ Infrequently

I) Was it clear from the communication heard on the video tape what the intentions were:

1) Of the anesthesia team?

Clear _____ Unclear

2) The surgical team?

Clear _____ Unclear

J) Was it clear what the patient's injuries were, and how the team was managing the patient?

Clear _____ Unclear

XIII) Communication Overview

(if a specific incident of poor communication, explain under appropriate analog scale)

A) Was needed information communicated among the anesthesia team?

Effective _____ Poor
Communication _____ Communication

B) Between anesthesia team and surgical team?

Effective _____ Poor
Communication _____ Communication

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.10 of 11).

11

C) How much extraneous chatter was there?

No extraneous chatter _____ lots of extraneous chatter

D) Were tasks delegated appropriately?

Ideal task delegation _____ Poor task delegation

E) Were requests for information made by the anesthesia team responded to?

Always _____ Never

F) Were requests for info made by the surgeons responded to?

Always _____ Never

G) Were anesthesia management strategies communicated effectively?

Effectively _____ Poorly

H) Was surgical management strategy communicated effectively?

Effectively _____ Poorly

COMMENT here on noteworthy aspects of video!

j:\users\navyans\vrdata\LOTASGUP.
2/09/94

Figure I.2. Intubation Analysis Questionnaire (IA) (continued - p.11 of 11).

SME Subjective Ratings		Case #__
SME/Pass:	-----	
Time:	-----	
Noise:	-----	
Team Int. NonAnesthesia:	-----	
Team Int. Anesthesia:	-----	
Time Constraints:	-----	
Task Workload:	-----	
Diagnostic Uncertainty:	-----	
Overall Stress:	-----	
SME/Pass:	-----	
Time:	-----	
Noise:	-----	
Team Int. NonAnesthesia:	-----	
Team Int. Anesthesia:	-----	
Time Constraints:	-----	
Task Workload:	-----	
Diagnostic Uncertainty:	-----	
Overall Stress:	-----	
SME/Pass:	-----	
Time:	-----	
Noise:	-----	
Team Int. NonAnesthesia:	-----	
Team Int. Anesthesia:	-----	
Time Constraints:	-----	
Task Workload:	-----	
Diagnostic Uncertainty:	-----	
Overall Stress:	-----	
SME/Pass:	-----	
Time:	-----	
Noise:	-----	
Team Int. NonAnesthesia:	-----	
Team Int. Anesthesia:	-----	
Time Constraints:	-----	
Task Workload:	-----	
Diagnostic Uncertainty:	-----	
Overall Stress:	-----	
SME/Pass:	-----	
Time:	-----	
Noise:	-----	
Team Int. NonAnesthesia:	-----	
Team Int. Anesthesia:	-----	
Time Constraints:	-----	
Task Workload:	-----	
Diagnostic Uncertainty:	-----	
Overall Stress:	-----	
SME/Pass:	-----	
Time:	-----	
Noise:	-----	
Team Int. NonAnesthesia:	-----	
Team Int. Anesthesia:	-----	
Time Constraints:	-----	
Task Workload:	-----	
Diagnostic Uncertainty:	-----	
Overall Stress:	-----	

Figure I.3: Stressor Collection Form

POST-VIDEO RECALL QUESTIONNAIRE Version 1.2

MIEMSS# ____ Date ____/____/____ Time since end of case was videotaped ____/____ Min/Hours
 Your SS# ____ How long since intubation was completed? ____/____ Min/Hours

Pre oxygenation by anesthesia mask? Y / N
 Approximate duration of pre oxygenation? ____ min ____ sec
 Circle monitors in use before intubation
 SaO₂ ETCO₂ BP ECG CVP PA Temp Nerve Stim Other
 In-line stabilization of C-spine? Y / N N/A
 Suction ready and immediately available? Y / N
 Suction used? Y / N
 Cricoid pressure used? Y / N N/A
 Cricoid pressure applied early or late (=after induction) (circle which)
 Cricoid pressure applied until cuff inflated ? Y / N
 Intubation equipment ready by patient's head? Y / N
 Neuromuscular block check before laryngoscopy? Y / N
 Did the patient cough, buck or move at any time during intubation? Y / N
 How many times did you pass the laryngoscopy? # ____
 If more than 1 attempt did you pre-oxygenate between? Y / N
 Did any O₂ desat occur (<95%) during intubation attempts? Y / N
 Was cuff inflated to 'just seal'? Y / N
 Was tube insertion distance checked? Y / N
 Was left and right side of chest auscultated? Y / N
 Was upper abdomen auscultated? Y / N
 Did you personally listen to the chest and abdomen (circle which)
 If cuff not inflated to just seal was it rechecked Y / N
 Was the tube taped or tied in position (circle which)
 How long did intubation take from preoxygenated cease to
 cuff inflation? ____ min ____ sec
 How long after induction of anesthesia was intubation achieved? ____ min ____ sec
 How long did intubation take from preoxygenation cease to tie or
 tape tube completion? ____ min ____ sec
 Was there any oral trauma? Y / N
 Do you recall HR, BP, SaO₂ or ETCO₂ values immediately before intubation?
 HR = BP = SaO₂ = ETCO₂ =
 Do you recall HR, BP, SaO₂ values immediately after intubation when
 tying or taping tube was just completed?
 HR = BP = SaO₂ = ETCO₂ =
 Did you protect the eyes? Y / N
 with tape / pads / eye ointment (circle which)
 Did you measure temperature? Y / N
 How long after anesthesia induction did you first record temp? ____ min ____ sec
 What was the first recorded temp ____ °C?
 When did you first look at the CO₂ monitor?
 <2 min after intubation >2 min after intubation (circle which)
 Please make comments about factors that may have affected recall
 eg. Stress, Fatigue, Excess Noise, Multiple Admissions, Critical Incident, Others(Identify below)

Please use back of form for comments.

aneseven.ts1
 revised 01/25/94

Figure I.4: Recall Questionnaire

Appendix II: Coding System for Verbal Communications and Activities

Last Updated 03/15/93

Ver. 2.1

OCS TOOLS CODES FOR DECISION-MAKING UNDER STRESS PROJECT

- o As described elsewhere, various subsets of codes are utilized in separate passes through the video tapes of interest.
- o In all passes, the liberal use of the OCS Comments field is encouraged.
- o In the case of the "behavioral" codes (i.e., Observation, Intervention, Activities, and Communication Behaviors) the agent of the behavior (i.e. the initiator) is coded with a two-character code prepended to the code used otherwise. Staff members are categorized as anesthesiologists, surgeons, other physicians, CRNAs, other nursing staff, and other technical staff (e.g., X-ray technicians). Staff members within each of these categories are numbered, e.g.:

A1 -- attending anesthesiologist

A2 -- assisting anesthesiologist or anesthesiology fellow

...

S1 -- attending surgeon

...

P1 -- other physician

...

C1 -- first CRNA to appear

...

N1 -- first nurse to appear

...

T1 -- first technician to appear

...

O1 -- officer or emergency medical tech

...

The numbering scheme applies to individuals throughout the case, and does not change as participants come and go during the treatment session. The intent is not to identify individuals per se, but to ascribe various behaviors and communications to the above categories of care givers.

- o In all instances where there is some uncertainty about which code to use (or which distinguishing character in a code), an "X" is used in place of the uncertain character(s).

Figure II.1: Coding System for Verbal Communications and Activities

Miscellaneous codes

- MC Miscellaneous *comment*; useful information or an opinion offered by the data analyst or by a subject matter expert (put content in OCS Comments field)
- ME Miscellaneous *event* worth noting but not otherwise captured by event codes (put content in OCS Comments field)
- MA Miscellaneous *activity* of participants worth noting but not otherwise captured behavior/performance codes (put content in OCS Comments field)

Physiological Events (these codes are entered with reference to the patient physiological data that is displayed on the video tape or with reference to the patient physiological data file that is logged on-site; normal and abnormal ranges are as defined in the LOTAS decision trees and task analyses)

- PH Heart rate abnormality
- PB Blood pressure abnormality
- PO Oxygen saturation abnormality
- PC End tidal CO₂ or other respiratory abnormality
- PT Body temperature abnormality
- PV Venous pressure abnormality

Codes for Monitoring the Data Strip on the Video

- MH Heart Rate appears on the data strip
- MB Pressure " "
- MO SaO₂ " "
- MC End tidal CO₂ " "
- MT Temperature " "
- MV Venous Pres. " "

Alarms Events

- AA Alarm, airway-related (i.e., ventilator, mass spec -- end tidal CO₂ pulse oximeter O₂ saturation)
- AC Alarm, circulatory-related (i.e., Mennen -- blood pressure, heart rate)
- AO Alarm, other equipment (e.g., IV infusion devices, etc)
- AE Alarm, external (e.g., intercom, pager, beeper, phone)

Figure II.1. Coding System for Verbal Communications and Activities (continued - p.2 of 5).

Observation Behaviors (these activities are often done in conjunction with interventions/manipulations; for coding purposes, intervention/manipulation codes should take precedence over observation codes; use observation codes only when an observation is apparent in the absence of a related manipulation/intervention)

- OP Observe, monitor, or check patient *directly* without reference to instrumentation or equipment
- OE Observe, monitor, or check the functioning of instrumentation or equipment *for other than the purpose of taking a reading* (e.g., observe integrity of oximetry sensor, blood pressure cuff, etc.)
- OR Observe, monitor, or check instrumentation or equipment *for the purpose of taking a reading* (e.g., take reading from Mennen)

Communication Behaviors

- CP Communicate with patient (meaningful communication between staff member and patient)
- CO Communicate with oneself (utterances that are seemingly "absent-minded"; i.e., not directed at teammates)
- CQ Ask a task-relevant question or ask for assistance
- CA Provide an answer or other direct response to an inquiry or request for assistance
- CQ2 Ask a task-relevant question or ask for assistance for a second time (let the digit reflect how many times the question was asked)
- CA2 Provide an answer or other direct response to an inquiry or request for assistance (let the digit reflect how many times the answer was given)
- CI Provide task-relevant information unsolicited
- CS Communicate a strategy, plan or schema
- CD Communicate a directive, give instructions, or delegate tasks, but not in a strategic sense
- CR Other task-relevant communication
- CN Non-task relevant communication (but directed at a teammate or at the patient)
- CU Unintelligible verbalization

Activity Behaviors (i.e., activities of the anesthesiology team)

- PA Preparatory activity (e.g., workstation set-up; mixing drugs)
- TA Treatment activity (direct, hands-on intervention with the patient)
- SA Supervisory activity (not hands-on intervention; directing the activity of teammates)
- RA Recording information activity (i.e., writing)
- NA Not actively involved but present in the environment (not necessarily in the cameras field of view)
- ZA Absent (after having been present previously)

Figure II.1. Coding System for Verbal Communications and Activities (continued - p.3 of 5).

Codes for Intubation

- TO Give oxygen (may use anesthesia mask, nasal, o2 tent, or non-rebreather.)
- TP Positioning the head and neck for intubation
- TC Apply cricoid pressure (Pressure applied by an assistant other than the person intubating; pressure applied with thumb and finger on neck at level of voice box.)
- TA Give intravenous drugs into I.V. infusion (usually pentothal and succinyl choline = "sux") to "induce" anesthesia.
- TS Suction of airway in the process of intubation (use other codes for suction at other times.)
- TL Laryngoscope in mouth. Suction may occur after laryngoscope inserted to allow clear visualization of larynx.
- TM Tube in mouth. Onotracheal intubation - conventional - preceded by laryngoscope.
- TN Tube in nose. (Nasotracheal intubation - note if right or left side - patient may have cervical spine injury - intubation maybe "blind" with no laryngoscope insertion.
- TU Cuff of tube inflated (Cuff up.)
- TH Hand ventilate with resusitator bay - observe chest then listen.
- TB Listen over both sides of chest (should see head move to right and left.)
- TO Listen over stomach (individual should reach down further out of camera view.)
- TV Connect ventilator.
- TB Listen over chest again to confirm ventilator is ventilating.
- TE Is Co2 signal appearing? (The end-tidal Co2 should be monitored to confirm the tracheal tube is in the trachea.)
- TT Tube taped in position.

Intervention/Manipulation Behaviors

- II Initial instrumentation of the patient; adding something new (e.g., attaching sensors, intubation, installation of arterial line, venous pressure sensor, or IV access)
- IS Manipulate sensors or other equipment already attached to the patient (i.e., after initial installation of that equipment) (e.g., take a blood pressure manually)
- ID Manipulate drugs or other anesthetic agents being given to the patient (by whatever route) OTHER THAN DRUGS BEING GIVEN TO FACILITATE INTUBATION
- IF Manipulate fluids being given to patient (other than blood) (this includes suctioning the patient) DO NOT USE THIS AS A SUCTION CODE DURING INTUBATION
- IB Manipulate blood being given to or taken from the patient (e.g., blood infusion to the patient, draw blood)
- IV Manipulate ventilator or other oxygen supply to the patient OTHER THAN DURING INTUBATION
- IH Other hands-on manipulation of the patient
- IE Manipulate equipment at other than the interface with the patient (e.g., set dials, calibration, silence or reset alarms)

Figure II.1. Coding System for Verbal Communications and Activities (continued - p.4 of 5).

The following coding schemes are used to transcribing audio tapes and to encode subjective ratings. Recording the anesthesiologist remarks on to audio tape and coding their subjective ratings into OCS can be done at the same time. You may not get all of the comments into OCS while the they are reviewing the video tape, so use the audio tape to fill in the remaining comments in the OCS file.

Codes for Transcribing Audio Tapes - when transcribing audio tapes use the following codes for SME (subject matter expert) comments

- SMEA1C The first three characters indicate it is a SME. The fourth character indicates the SME is the attending and the last character indicates this is a transcribed comment.
- SMEB1C This is used for an SME pass with a non-attending anesthesiologist
- SMEB2C This is used for asecond SME pass with a non-attending anesthesiologist

Codes for Subjective ratings

- SRA13 This five character code is used for subjective ratings. The first two characters (SR) indicate that this is a subjective rating. The next character (A) indicates the rater is the attending anesthesiologist (use a B if it is the second rating pass with another anesthesiologist). The fourth character indicates which item is being rated (e.g. noise, diagnostic uncertainty). The final character is the rating (1-5) on the scale.
- SRB26 This "B" in this code is used when a second anesthesiologist rates the case.

Codes for Number of People working on the Case

- NP32 The first two characters refer to Number of People working on the case. The next two characters are digits. The first digit indicates how many members of the anethsia team are on camera. The last digit indicates how many of the members of the anethsia team on camera are actively working on the case.

j:\users\navyans\doc\locscodes.doc

Figure II.1. Coding System for Verbal Communications and Activities (continued - p.5 of 5).

Appendix III: Case Example

Patient had gun shot wounds (GSW) to the abdomen and was an IV drug abuser. Profound hypotension, second to lacerating vessel injuries. Patient arrived disoriented and combative and were in need of massive transfusion. Blind nasal intubation was attempted, along with succinylcholine in tongue, followed by oral intubation attempt. Patient vomited during airway management at risk for aspiration.

Patient injury scores upon admission: Abbreviated Injury Scores (AIS) = 5; Glasgow Coma Scale (GCS) = 9; TAG=4; TI = 14; American Society of Anesthesiologists (ASA) = 5.

Included here are

- Transcriptions of the verbal communication
- Transcriptions of subjective matter experts
- Patient admission record
- Intraoperative anesthesia record
- Laboratory analysis, hematology, and biochemistry data.
- Operative and discharge summary
- Fluid infusion records

OCS DATASET REPORT

DATASET FILE: 41COMM.DAT
DESCRIPTION: Communications pass.

OUTPUT FILE: 41COMM.OCS

RECORD TIME	CODE	DESCRIPTION
1	00:00:00.00	start
2	00:00:01.17	mc (A1 = Dr. XXXX)
3	00:00:01.20	mc
4	00:00:01.23	mc (S1 = Dr. XXXX; male attending surgeon)
5	00:00:01.27	mc (S2 = Dr. XXXX; female fellow/resident entering screen at 23:30)
6	00:00:01.28	mc (S3 = male surgeon; team leader)
7	00:00:01.30	mc
8	00:00:01.33	mc (N1 = ?)
9	00:00:01.37	mc (N2 = ?)
10	00:00:01.40	mc (N3 = Steve) male nurse
11	00:00:01.43	mc (N4 = ?) male nurse
12	00:00:01.44	mc
13	00:00:01.47	mc (C1 = J. XXXX)
14	00:00:01.50	mc (C2 = J. XXXX)
15	00:00:01.51	mc
16	00:00:01.53	mc (R1 = ?) x-ray technician, male voice
17	00:00:01.54	mc
18	00:00:01.57	mc (T1 = ?) female EMT; voice heard at the beginning of the tape.
19	00:00:01.61	mc (T2 = XXXX) OR staff.
20	00:00:01.63	mc
21	00:00:01.67	mc [Communication Pass Begins 00:10:48.22]
22	00:00:01.70	mc [Communication Pass Stops 00:28:42.05]
23	00:00:01.73	mc [Pre-ox @ 00:11:17.00] [Tube taped down @ 00:18:51.00]
24	00:00:01.77	mc
25	00:00:01.80	mc
26	00:10:41.70	xxxxci "... minimal response ..."
27	00:10:48.73	BEGIN.... (Communication pass begins @ patient arrival)
28	00:10:48.77	tltmci "He's very combative, too, you might have to restrain him."
29	00:10:53.97	altlclq "Got an I.V. in?"
30	00:10:54.77	s2tmccq " ... no I.V.?"
31	00:10:55.33	tlalca "No, I couldn't get one."
32	00:10:56.43	s2tmcs "Probably have to put him to sleep is what we're going to have to do because I think he might be close to [death]."
33	00:11:02.33	s2clclq "Ready?"
34	00:11:02.57	cls2cs "All right, on three"
35	00:11:03.07	s2clcs "One, two, three."
36	00:11:03.93	cls2cs " ... one, two, three."
37	00:11:06.43	s2xxci "If you don't feel a pulse, you're open[ing] the chest."
38	00:11:08.03	s2xxcd "...get me the cut-down."
39	00:11:11.40	s2tmcl "I don't have a groin pulse"
40	00:11:13.87	clwccq "Who's got the oxygen...?"
41	00:11:14.77	s2tlcd "Move this out of the way."
42	00:11:14.80	s2tlcd "Get this out of the way."
43	00:11:16.13	nntlcd "Take this out of the way."
44	00:11:17.50	slxxci "We need"
45	00:11:17.63	tltmci "I have no idea what his name is, only that he's thirty."
46	00:11:19.40	s2tlcr "O.K., fine"
47	00:11:22.47	clc2cq "[Do you have] the oxygen turned on?"
48	00:11:23.30	xxxxcn "Sorry."
49	00:11:25.27	s2tlcd "Get this out of the way."

Figure III.1: Transcriptions of the verbal communication and codings for the example case

50	00:11:31.17	slooco	"C'mon."
51	00:11:32.13	clxxcu	.
52	00:11:33.63	xxcum	.
53	00:11:36.80	slxxci	"... we don't have I.V."
54	00:11:41.20	sltmcq	"Does he have a pulse or not?"
55	00:11:41.63	clcul	.
56	00:11:44.77	clslna	(C1 nods affirmatively.)
57	00:11:45.20	nls1ci	"I have a minimal ... pulse."
58	00:11:46.73	sltmcq	"Does he have a blood pressure?"
59	00:11:47.93	clslna	(C1 shakes his head negatively.)
60	00:11:48.97	als1ci	"He's [fairly] hypotensive."
61	00:11:49.57	xxxxci	"I don't have it."
62	00:11:52.13	s2s1ca	"He's got a little groin pulse."
63	00:11:53.67	slclcs	"Intubate him."
64	00:11:54.73	slxxcd	"Don't move, don't move." (Directed to person on whose back S1 is opening some package.)
65	00:11:57.80	clslci	"No, he's not going to let me..."
66	00:11:58.03	alc1cq	"Not, he's going to let you?"
67	00:11:58.80	slaacs	"Well paralyze him then."
68	00:12:00.17	clslna	(C1 shakes his head negatively.)
69	00:12:00.87	slclcq	[Got an i.v. in him?]
70	00:12:01.61	s3tnci	"He's not movin' a whole lot.... shut down over here and he didn't move."
71	00:12:05.61	xxnncq	"You've got a Cordis tray over here?"
72	00:12:09.33	nnxxca	"I've got a Cordis over here..."
73	00:12:10.03	slwwcq	"Uum, who's got scissors? Anyone got scissors?"
74	00:12:10.90	n3s1ca	(Unintelligible answer.)
75	00:12:12.20	sln3ca	"O.K."
76	00:12:13.90	s2sscq	"Need to open his chest guys?"
77	00:12:14.67	sls2cq	"Does he have a pressure on the groin?"
78	00:12:17.17	s2s1ca	"I felt a very, very faint pressure..."
79	00:12:17.97	clxxcq	"Can you get me some ... ?"
80	00:12:21.53	slssca	"Let's open his chest then if he's got a pressure of less than ninety."
81	00:12:23.30	slzzcq	"Where's the..."
82	00:12:23.53	nxcul	.
83	00:12:24.93	clslca	"Down here."
84	00:12:25.37	als1ci	(A1 unintelligibly provides information to s1.)
85	00:12:26.40	slalca	"O.K., hold on."
86	00:12:27.47	sln3cn	"Here are your scissors back."
87	00:12:29.20	xxxxcq	"Is it open?"
88	00:12:29.97	xxxxcq	"Where do I get an I.V. bag?"
89	00:12:30.30	sltmcq	"Now, is that...?"
90	00:12:32.57	sls2cq	"Nadine, you workin' on the i.v. down there?"
91	00:12:33.30	s2s1ca	"I'm trying."
92	00:12:34.13	alc1cd	"Stick this in the tongue."
93	00:12:38.63	clalca	(Unintelligible answer.)
94	00:12:42.17	nnxxcq	"Where are you?"
95	00:12:44.17	xxcum	.
96	00:12:48.70	xxxxca	"Oh yea, yea, we did, we..."
97	00:12:55.87	xxcum	.
98	00:13:06.93	slclcq	"Is he breathing at all?"
99	00:13:12.43	als2cq	"You got a line down there yet?"
100	00:13:14.97	nnocco	"Ouch, ow..."
101	00:13:15.03	c2clcr	"Here you go." (C2 has suction.)
102	00:13:16.50	slxxcu	.
103	00:13:19.13	s3tmcq	"Has he got ...?"
104	00:13:20.33	s2s3ca	[We have no I.V. access.]
105	00:13:21.67	sls2cq	"He has no I.V. access?"
106	00:13:25.37	xxzzcn	"(Next) patient's here."
107	00:13:25.93	xxxxca	"O.K."
108	00:13:28.70	xxcum	.
109	00:13:29.67	xxxxcq	[Can we go over here?]
110	00:13:30.77	xxxxca	[It gets crowded.]
111	00:13:31.37	alcum	(Appears to be saying something to c1.)
112	00:13:32.87	xxcq	"What can you do on the ... ?"
113	00:13:36.57	xxcum	.
114	00:13:39.37	xxcs	"... we've got to get in here..."

Figure III.1. Transcriptions of the verbal communication and codings for the example case (continued - p.2 of 8).

115	00:13:40.00	mc	(Sound of patient vomiting)
116	00:13:41.70	xxcr	"Let me get you"
117	00:13:43.90	xxcs	"O.K., you get the"
118	00:13:44.63	nxci	"[Horace], I'm going to get under this."
119	00:13:45.97	xxcd	"More ... over here."
120	00:13:54.03	xxci	"We need one, one, uh, three ... O.K."
121	00:13:56.13	xxcq	"... other one here?"
122	00:13:57.07	xxca	"Yea."
123	00:14:04.47	ssxxcs	"What we're going to need is, some sort of...you know...line..."
124	00:14:06.10	nxcr	"_____, watch out."
125	00:14:10.13	xxcum	.
126	00:14:12.17	xxcum	(During the past 30 seconds, approximately, there was a considerable amount of unintelligible communication between al, cl, and person in green shirt. They were huddled around pt's head and, at this time, pt. is vomiting.)
127	00:14:13.83	s2tmcq	"We get a line yet, you guys?...we gotta have a line in ..."
128	00:14:14.87	alca	"Thank you."
129	00:14:17.47	n3s2cq	"Do you want a Cortis?"
130	00:14:19.63	s2n3ca	"Yea, I got a Cortis, I just want..."
131	00:14:20.63	xxca	"Oh yea, yea, that's fine..."
132	00:14:20.67	c2cul	(C2 appears to say something to cl. Unintelligible, however.)
133	00:14:21.70	n1sscq	"Do we want a c.p.i.?"
134	00:14:23.13	slca	"Ah, yea."
135	00:14:28.37	xxcq	"...c.p.i.?"
136	00:14:29.40	slca	"No, we're going to do that, we're going to do that."
137	00:14:30.37	slclcq	"Is he [talking]?"
138	00:14:31.47	clca	"Mmm-hmm." (Affirmative answer.)
139	00:14:32.90	alcq	"Are you O.K.?"
140	00:14:34.50	s3tmcd	"Keep him down."
141	00:14:36.90	n2cp	"Hey buddy, you best hold your ass still, alright?"
142	00:14:43.33	sln3cd	"Steve, want to do me a favor? Get a fat boy cuff for me."
143	00:14:43.40	c2cq	"John?" (C2 shows cl a particular piece of equipment, either tube or something having to do with tube.)
144	00:14:44.57	clca	"Yea." (Affirmatively answering that c2 is holding the right piece of equipment.)
145	00:14:45.03	n3ca	"What?"
146	00:14:46.10	alcn	"Hey!" (Patient rises up off the bed a bit.)
147	00:14:46.27	sln3ca	"A fat boy cuff."
148	00:14:47.20	xxxxcd	"Hold him down, hold him down, hold him down."
149	00:14:49.17	clcs	"Let's do something" (Speaking to al.)
150	00:14:49.93	xxcq	"Where are they at, Steve?"
151	00:14:50.30	alcn	"O.K., uum"
152	00:14:51.77	n3nncl	"Just ask anybody."
153	00:14:52.37	xxcq	"What do you need?"
154	00:14:53.67	xxca	"A fat boy cuff."
155	00:14:54.07	xxcn	"Oh, I know where they are, I know where they are."
156	00:14:56.80	slci	"O.K., we've gotta get him"
157	00:14:57.97	xxcum	.
158	00:15:00.20	slalcd	"Let's get the I.V. going so we can paralyze the..."
159	00:15:04.40	alcu1	.
160	00:15:07.13	sln3cd	"O.K., hold him down so we can get him paralyzed and then we can work with him."
161	00:15:07.50	xxca	"Got it."
162	00:15:10.23	slxxcq	"Breath sounds in the left chest?"
163	00:15:12.93	slxxcq	"Are there breath sounds in left chest?"
164	00:15:16.10	xxca	"Mm-minor, mild."

Figure III.1. Transcriptions of the verbal communication and codings for the example case (continued - p.3 of 8).

165	00:15:16.40	xxcul	.
166	00:15:21.33	nxcul	.
167	00:15:21.63	alid	a1 induces via iv line
168	00:15:23.10	xxcn	(Background laughter.)
169	00:15:23.40	altmci	"O.K., succinyl choline is in, cricoid pressure's going on."
170	00:15:24.73	s1cul	.
171	00:15:28.13	s2xcn	(More background laughter.)
172	00:15:28.33	s2wwcd	"O.K., someone move the light over here."
173	00:15:30.73	alcq	[About how long ago ...?]
174	00:15:31.83	clca	(Unintelligible answer; c1 shakes his head negatively.)
175	00:15:32.07	xxcum	.
176	00:15:34.47	n3nnnci	[... called for a fat boy cuff.]
177	00:15:35.10	nnn3ci	"They don't have any in there."
178	00:15:37.03	xxcd	"Somebody's got to get..."
179	00:15:43.00	xxcum	.
180	00:15:44.00	xxcq	"Uum, _____, you got 'em?"
181	00:15:44.77	xxca	"No."
182	00:15:46.27	alcu1	(Unintelligible communication b/t a1 and c1.)
183	00:15:46.33	xxcr	"... the cut down."
184	00:15:55.87	xxcum	(Background conversations, for the most part; the 'major players' don't seem to be saying much right now.)
185	00:16:00.47	alci	"I've got this running."
186	00:16:03.93	nxcr	"Watch out."
187	00:16:10.00	clcu1	.
188	00:16:12.00	sxcq	(Unintelligible question directed at c1.)
189	00:16:14.27	clca	(Unintelligible response.)
190	00:16:16.23	nxcq	"Do you want ...?"
191	00:16:17.57	sxcu	"O.K., I'll"
192	00:16:19.90	s2nnnci	"We need another Cortis."
193	00:16:22.33	s1s2ci	"You've got a Cordis right behind you."
194	00:16:35.27	xxcum	(Quite a bit of unintelligible communication among several people.)
195	00:16:37.13	clalcq	"Got the sux [running]?"
196	00:16:37.23	alc1ca	"Yea."
197	00:16:40.17	s1cr	"We're shootin' him a little bit now..."
198	00:16:40.61	clcq	(Unintelligible question directed at a1.)
199	00:16:41.07	alca	(Unintelligible answer directed at c1.)
200	00:16:44.33	alcd	"Somebody put another liter of fluid over here for me."
201	00:16:46.03	s1xxcq	"Are breath sounds [gone]?"
202	00:16:47.73	clca	(Unintelligible answer, c1 shakes his head negatively; not exactly sure which question he's answering.)
203	00:16:48.63	s1clcd	"Tell me when he's intubated 'cause I don't know."
204	00:16:51.63	s1aacq	"Oh, he's not intubated?"
205	00:16:54.50	als1ci	"He's just taken about a minute and a half for the drugs to ..."
206	00:16:55.90	s1alc1	"Some of it might have ended up in here, too."
207	00:16:59.90	s1ci	"It's just that I didn't have the vein totally..."
208	00:17:00.00	mc	"Ambu mask off."
209	00:17:00.87	xxcum	.
210	00:17:02.30	alt2cq	[Need some more?]
211	00:17:05.61	alcu1	.
212	00:17:14.53	alcum	(Unintelligible communication b/t a1 and c1 but cannot here due to general background noise/conversations and suctioning.)
213	00:17:17.13	sxc1	"... line coming down from the bottom.)
214	00:17:20.00	mc	(Laryngoscopy)
215	00:17:25.70	xxcum	(General background noise; again, all the 'major players' seem to be quiet.)
216	00:17:36.23	clii	(C1 successfully inserts intubation tube

Figure III.1. Transcriptions of the verbal communication and codings for the example case (continued - p.4 of 8).

217	00:17:37.13	xxcq	in pt.)
218	00:17:38.83	alcu1	"...ever get...blood pressure...?"
219	00:17:48.73	xxaaci	(al asks an unintelligible question.)
220	00:17:50.61	alnncq	"You have breath sounds on the left."
221	00:17:52.70	xxaaca	"Breaths on both sides?"
222	00:17:53.97	alcu1	"Breath sounds on the right."
			(Al says something unintelligible to
			cl.)
223	00:17:55.93	cicu1	(Cl says something unintelligible to
			al.)
224	00:18:00.00	aa	(Ventilator alarm sounds)
225	00:18:06.00	mc	(Ventilator connected)
226	00:18:07.00	xxcum	(At this point, seems very noisy: lots
			of conversations among many people, at
			least two alarms which are alarming, and
			the overhead p.a. system can be heard
			rather easily.)
227	00:18:09.10	alcq	"Can you put one up?"
228	00:18:10.93	t2ca	"I got one up right now."
229	00:18:11.57	alcn	"Good man."
230	00:18:13.73	xxcq	"Do you want some ... for that?"
231	00:18:14.61	alcq	"Do we have a pressure over there, yet?"
232	00:18:16.43	c1ca	"Yea, uh, yea." (Probably answering
			unidentified woman's question, not al's
			question.)
233	00:18:16.83	xxca	"No we have not." (Probably an answer to
			al's question.)
234	00:18:18.23	xxci	"... zero over zero ..."
235	00:18:20.50	alcq	"Do you have the...uh...o-positive?"
236	00:18:22.30	xxcd	"I need an eleven blade and a Cortis."
237	00:18:24.61	xxci	"It's got to be an eleven blade..."
238	00:18:26.50	alcq	"O-positive please!"
239	00:18:27.57	xxcum	.
240	00:18:29.07	xxci	"Got it."
241	00:18:29.97	n2cq	"Can you get an eleven blade?"
242	00:18:31.03	xxca	"We got it, we got it."
243	00:18:32.40	n2cd	"Never mind, she's got it."
244	00:18:32.97	xxcr	"I'm not sure ..."
245	00:18:34.17	xxcq	"Steve, you need a bigger cuff?"
246	00:18:36.27	n3ca	"Huh? No, ...just got one."
247	00:18:45.47	xxcum	.
248	00:18:56.40	alcu1	(Al saying something unintelligible to
			t2.)
249	00:18:59.17	t2cu1	(T2 saying something unintelligible to
			al.)
250	00:19:02.07	xxcq	"Do we have a pressure yet?"
251	00:19:04.13	xxca	"Not yet."
252	00:19:04.80	xxcq	[We're in the ..., right?]
253	00:19:13.57	xxcq	"Mike? Two units checked." (Someone
			wants al's attention to hand him blood.)
254	00:19:18.77	n2cn	"I don't think you got a core sampling."
255	00:19:26.10	slcs	"We'll need x-rays next..."
256	00:19:26.17	r1ca	"Right here."
257	00:19:31.10	slcs	"...as soon as Dr. Seimer and
			company have finished, uh, with the
			I.V...."
258	00:19:34.80	slcs	"...x-rays of the abdomen and..."
259	00:19:37.47	clii	tube tied in place
260	00:19:37.70	slcq	"...and a foley...you...catheter in...?"
261	00:19:37.93	xxca	"We got [close]."
262	00:19:39.13	xxcq	(Unintelligible question.)
263	00:19:40.30	xxca	"Yup, tonight."
264	00:19:42.83	xxcq	"Mike?"
265	00:19:45.13	alcn	"... we've got a light ... over
			there ..."
266	00:19:47.23	xxcu1	.
267	00:19:49.70	xxcn	(Laughter.)
268	00:19:51.73	n4cq	"Can we, uh...?"
269	00:19:54.50	alcu1	"You can trace that straight in
			there, Michael. I'll be right back ..."
			(Then I'll let you get on)
270	00:19:56.07	clcd	"This has to come off ... here, just

Figure III.1. Transcriptions of the verbal communication and codings for the example case (continued - p.5 of 8).

271	00:19:59.30	xxcr	hold the cap ..."
272	00:20:01.00	mc	"Here you go."
273	00:20:01.87	xxcum	(...I'm sorry...)
274	00:20:04.73	xxcq	.
275	00:20:05.97	xxca	"Is there a reason that had to be done?"
276	00:20:07.97	n2cr	"Yes there is."
			"You can't [make] ... you can't use it after that."
277	00:20:08.40	xxcul	.
278	00:20:16.61	xxcum	.
279	00:20:20.13	xxcul	.
280	00:20:21.23	xxcq	"What does that mean?"
281	00:20:22.00	mc	(20 x 20 Er, you don't want this?)
282	00:20:22.63	xxcn	"Yea, I got ..."
283	00:20:24.07	xxcq	"Why can't [there be] ...?"
284	00:20:26.40	n2ca	"Because that reduces it to an eighteen-gauge I.V."
285	00:20:27.43	xxcn	"This doesn't."
286	00:20:30.47	n2cn	"Sorry but the side...does."
287	00:20:31.27	xxcn	"O.K."
288	00:20:37.00	n2cd	"Study the number of times [today] ..."
289	00:20:37.37	xxcul	.
290	00:20:40.23	xxcn	"Then you have to undo it."
291	00:20:41.50	alcq	"Did we get a pressure?"
292	00:20:43.61	xxcn	"They said you can't put the...."
293	00:20:44.40	xxci	"We have ..."
294	00:20:45.00	xxcn	"We'll figure it out..."
295	00:20:47.63	alcq	"We need a line above his diaphragm..."
296	00:20:51.50	n2ci	"I need a Cortis but I think..."
297	00:20:53.53	alcq	"O.K., subclavion on this side?"
298	00:20:54.53	c1ca	"I think we do."
299	00:20:57.87	xxcs	"Alright, we need to put a chest tube in his side."
300	00:21:01.80	xxci	"We just need to get another..."
301	00:21:05.27	uycq	"Did we ever get a...blood pressure?"
302	00:21:07.13	n2ca	[No.]
303	00:21:09.10	xxcq	"We need what?"
304	00:21:09.87	xxci	"Remember, he hit a ..."
305	00:21:10.17	alca	"More"
306	00:21:10.70	xxcq	"Did we ever get a blood pressure?"
307	00:21:13.07	alcq	"Just hang on to it for awhile."
308	00:21:15.80	c1cq	(C1 asks an unintelligible question of al.)
309	00:21:18.50	alca	"We'll have to... in a minute; be nice to see what it will be ..."
310	00:21:20.37	xxcq	"...can't we get a regular cuff? We had one."
311	00:21:22.00	n2ca	"I'd like to but I don't have one."
312	00:21:23.93	xxcn	"We should have one, just tell 'em to get one; we don't even have any blood pressure and the guy's been here ten minutes."
313	00:21:26.97	alcic	"Well we know... a bit before."
314	00:21:29.93	xxci	"Aah, he's ... the chest wall."
315	00:21:34.43	xxcq	"Who's minding?, Him? the chest?"
316	00:21:36.33	xxcq	(Unintelligible question.)
317	00:21:38.17	xxci	"No, I can't ... the belly. Yea, I know, I thought you were talkin' about the ..."
318	00:21:41.50	slci	"This is an abdominal..."
319	00:21:42.97	xxcr	"I know, but we put a needle in his chest."
320	00:21:43.83	xxcr	"I know, I know, I know."
321	00:21:45.13	xxcr	"That's why I'm afraid to ..."
322	00:21:49.23	xxcr	[C'mon, we have to get him back.]
323	00:21:52.00	xxcq	"Um, does he have, does he have ...?"
324	00:21:58.50	xxcum	(Several voices speaking at once, as well as softly.)
325	00:22:01.27	t2cul	.
326	00:22:04.13	xxcq	"... got a carotid pulse ... pressure, I'd say, of over a hundred."
327	00:22:06.50	xxcq	[What's the temperature?]

Figure III.1. Transcriptions of the verbal communication and codings for the example case (continued - p.6 of 8).

328	00:22:08.10	alci	"Yea."
329	00:22:10.13	alci	"He's actually, I mean ..."
330	00:22:12.93	xxcq	"They didn't ... him?"
331	00:22:13.90	alci	"... perfusing his (lungs)."
332	00:22:16.40	alcs	"Let's get a temperature program and we'll know where we are."
333	00:22:17.30	xxci	"... they may need"
334	00:22:18.00	xxcq	"Quite cold isn't it?"
335	00:22:19.93	xxcq	"Is that true ...?"
336	00:22:22.37	alcq	"Pass me that temperature ...?"
337	00:22:25.97	xxcum	.
338	00:22:28.87	xxcum	.
339	00:22:32.30	n2ci	"... and, therefore, we don't have the manual cuffs..." ^d
340	00:22:33.47	xxcq	"Steve?"
341	00:22:34.07	xxcq	"Steve, is this big enough?"
342	00:22:36.77	xxcq	"Steve?"
343	00:22:37.27	xxci	"It's not manual."
344	00:22:41.37	n3ci	"I've already tried sitting the..."
345	00:22:44.20	xxcum	.
346	00:22:46.93	xxcs	"We've got to get an upper ...temporary chest tube in or a subclavian...we've got to get an upper body link in."
347	00:22:58.07	xxcum	.
348	00:23:07.10	rlca	"OK, we'll try and get up at his nipple."
349	00:23:07.33	xxcq	(Unintelligible question.)
350	00:23:08.61	rlca	"No."
351	00:23:10.10	xxci	"It's over there."
352	00:23:10.33	rlvi	"... no bearing on ..."
353	00:23:14.77	xxcum	.
354	00:23:24.70	xxcd	"I'm going to need a Cortis...cannula ..."
355	00:23:27.20	xxcn	"We'll get a [doplar] right there. Ha ha ha."
356	00:23:31.13	alci	"You can feel the leak in there."
357	00:23:32.97	s2cq	"Is the belly open now?"
358	00:23:33.90	xxci	"He was stabbed once."
359	00:23:35.10	xxcq	"Where's he stabbed?"
360	00:23:35.77	xxcul	.
361	00:23:39.80	xxci	"He's stabbed right in the middle of the abdomen and it doesn't go very far."
362	00:23:41.03	s2cq	"Does he have belly pain?"
363	00:23:42.53	xxca	"No ..."
364	00:23:48.23	n2ci	"[He's] got a pulse; he's got a good carotid."
365	00:23:54.03	alcr	"The EKG...that one."(CO2)
366	00:24:10.67	s2cq	"Do we have a pressure?"
367	00:24:11.77	uyca	"Yea, there's a..."
368	00:24:13.80	s2cq2	"Did we get a blood pressure?"
369	00:24:21.83	alcq	"Can I have some warm plasmalyte?"
370	00:24:22.87	alcq	"Thanks, Robbie."
371	00:24:35.07	s2cq	"Are you in the...?"
372	00:24:38.23	s1ca	"I think I'd rather have a ... than..."
373	00:24:40.70	s2ca	"Yea, that's why you..."
374	00:24:48.00	n1cd	"You may need this EKG lead moved..."
375	00:24:49.37	alcq	"Thank you."
376	00:24:49.37	s2ci	"Then you just..."
377	00:24:52.47	s2cd	"...need this moved so I can put in a subclavian."
378	00:24:55.73	uxci	"OK...line in."
379	00:24:58.80	uxcr	"It worked before we got here."
380	00:25:02.77	s1cq	"Are you ready to hook up that...?"
381	00:25:03.00	mc	(Either make it bigger or...)
382	00:25:04.80	s2cs	"...or get it in."
383	00:25:09.50	s1cs	"Please don't use that clamp..."
384	00:25:12.50	uxca	"Uh, OK."
385	00:25:21.40	s2cq	"Did the whole monitor go down?"
386	00:25:36.50	s2cs	"Can we move this, I'm going to try and..."
387	00:25:40.00	alcq	"Can I have another dot..."

Figure III.1. Transcriptions of the verbal communication and codings for the example case (continued - p.7 of 8).

388	00:25:56.00	xxcn	"Nice shot"
389	00:25:59.33	uxci	"A hundred over forty-six."
390	00:26:02.50	uxcq	"Nadine? A hundred over forty-six?"
391	00:26:03.27	s2ca	"Great, thanks."
392	00:26:09.20	alci	"We've had one, two, three liters of crystalloid, two units of red cells ..."
393	00:26:14.83	s1cs	"Now, any tube, I really don't care."
394	00:26:18.37	s2cq	"Do we have a number two for the line that need a suture?"
395	00:26:29.87	uxcq	"Got power?"
396	00:26:31.23	uxca	"Yea."
397	00:26:48.40	s2cq	"...sutures?"
398	00:26:52.70	alcs	"Do you, thank you...probably just hang loose for a minute...see what we're doing."
399	00:26:59.03	s2cr	"Whoever did that...that's great...that's nice work."
400	00:27:02.61	uycn	"This is not a pretty picture."
401	00:27:09.57	uxci	"Got number two."
402	00:27:27.00	aa	(Vent Alarm)
403	00:27:43.00	mc	(Chest auscultated by al ?vent d/c...)
404	00:27:46.90	uycq	"Mike, is there any way we can fix that EKG machine?"
405	00:27:47.53	alca	"Hmm?"
406	00:27:49.50	uycq2	"Is there anyway we can fix that EKG machine?"
407	00:27:55.23	uycq	"Is it tight up here?"
408	00:28:02.80	uycn	"Halleluliah."
409	00:28:06.80	s2cq	"Can you move his head a little bit for me?"
410	00:28:10.03	alca	"Yea; we could actually roll him over (on the bed a little bit...)"
411	00:28:10.67	s1cq	"Nadine?"
412	00:28:11.10	s2ca	"Uh-huh?"
413	00:28:14.03	s1cs	"I think we should get some quick films taken..."
414	00:28:15.40	s2ca	"I'm just going to try to get an upper line ...cer I'm just ..."
415	00:28:18.43	s1ca	"Fine, you just figure out where."
416	00:28:26.70	r1cs	"OK, you want me to get your place ready...because we need a chest..."
417	00:28:28.93	uxcs	"We're going to get him straightened up a little bit on the..."
418	00:28:31.67	r1cs	"We're going to use this machine for the abdomen."
419	00:28:33.00	mc	(Watch the slide)
420	00:28:38.40	r1cs	"Actually, I...everybody out."
421	00:28:42.10	uxcs	"Alright, as soon as your done putting the chest tube in, we'll get him straightened out here..."
422	00:28:42.17	STOP.....	(Communication pass stops @ approximately ten minutes after intubation is complete)
423	10:00:00.00	end	.

Figure III.1. Transcriptions of the verbal communication and codings for the example case (continued - p.8 of 8).

OCS DATASET REPORT

DATASET FILE: 41AN.DAT
 DESCRIPTION: Annotations

OUTPUT FILE: 41AN.OCS

@

RECORD	TIME	CODE	DESCRIPTION
1	00:10:46.13	a	Nursel arrives at scene.
2	00:10:46.13	start	.
3	00:11:00.50	a	The patient is transported onto table
4	00:11:00.50	a	emergency medicine fellow tests her stethoscope and is ready to examine the patient.
5	00:11:00.50	a	emergency medicine fellow is helping the transport of the patient.
6	00:11:00.50	a	The patient is pushing CRNA
7	00:11:07.87	a	the patient is now on the table.
8	00:11:07.87	a	emergency medicine fellow is examining the patient with auscultation.
9	00:11:12.57	a	Nursel brings over an airmask.
10	00:11:15.37	a	CRNA brings over the oxygen tube and connects it to the airmask.
11	00:11:17.23	a	CRNA applies the oxygen mask on to the patient, while the emergency medicine fellow is still examining the patient.
12	00:11:19.53	a	CRNA is checking the lines.
13	00:11:19.53	a	Surgeon appears in the scene.
14	00:11:22.61	a	surgeon starts examining the patient with stethoscope.
15	00:11:22.61	a	CRNA is bagging the patient with the ambubag.
16	00:11:33.27	a	Nursel is preparing something at the back of the anesthesiologist.
17	00:11:33.27	a	emergency medicine fellow, the CRNA, and the surgeon is re-positioning the patient, as they have the primary access to the patient's head area.
18	00:11:39.07	a	CRNA resumes bagging the patient after re-positioning the patient.
19	00:11:45.33	a	Surgeon2 enters the scene, and informs the anesthesiologist his presence.
20	00:11:51.70	a	CRNA takes off oxygen mask and picks up laryngoscope.
21	00:11:55.20	a	Surgeon2 puts gloves on.
22	00:11:56.00	a	CRNA is attempting laryngoscopy
23	00:11:56.00	a	emergency medicine fellow is waiting for opportunity for her to examine the patient again. She has the stethoscope ready in her hand.
24	00:11:58.33	a	Anesthesiologist enters scene, and grabs a syringe from the drug cart.
25	00:11:58.67	a	CRNA drops off laryngoscope after failed laryngoscopy (patient is not relaxed enough), and applies oxygen mask again.
26	00:11:58.68	end	.
27	00:12:00.43	a	Surgeon seems to inquire about the possibility of trying to intubate without i.v. access. CRNA answers negatively by shaking head.
28	00:12:02.87	a	anesthesiologist is preparing sux
29	00:12:09.63	a	anesthesiologist puts back the prepared sringe (sux in it).
30	00:12:09.63	a	emergency medicine fellow attempts again stethoscopy.
31	00:12:13.47	a	CRNA looks around for something.

Figure III.2: Transcriptions of the commentaries by the attending anesthesiologist who participated in the care in the example case

32	00:12:13*80 a	the surgeon is trying the iv at subclavian area.
33	00:12:17*20 a	anesthesiologist bends down and checks something (the progress of iv placement?)
34	00:12:18*13 a	CRNA is asking for something (seems to be the lubricant for naso-intubation)
35	00:12:22*33 a	CRNA is pointing to the thing that he wants (lubracant?)
36	00:12:23*37 a	CRNA seems to ask for lubracant for naso-intubation.
37	00:12:28*63 a	Nurse brings over the (lubracant?) over.
38	00:12:29*57 a	Nurse is passing the lubracant.
39	00:12:29*57 a	CRNA puts the ETT to a nearer place.
40	00:12:29*77 s	anesthesiologist picks up a sringe (probably sux?)
41	00:12:35*23 a	anesthesiologist asks CRNA for access to the patient, with a syringe in his hand.
42	00:12:36*61 a	Nurse has an ETT in his hand and is ready to cooperate with CRNA with naso-intubation.
43	00:12:37*80 a	CRNA is applying lubracant onto the patient's nose.
44	00:12:40*03 a	CRNA is pulling out the ETT.
45	00:12:42*63 a	anesthesiologist injects sux into the patient's tongue.
46	00:12:45*37 a	CRNA starts inserting nasal tube.
47	00:12:50*03 a	Nurse is ready to connect a tube (oxygen line?)
48	00:12:51*83 a	Anesthesiologist bends down to watch the progress of nasal intubation.
49	00:12:54*77 a	Patient reacts to the insertion of nasal tube and making gagging noise.
50	00:12:55*33 a	Nurse drops the oxygen tube, turns around, and looks for suctioning tube.
51	00:12:57*93 a	CRNA still attempts to push the nasal tube down.
52	00:13:05*17 a	CRNA appears to have difficulty in inserting the tube, but still trying to insert the nasal tube.
53	00:13:08*61 a	The surgical team is trying to establish iv access. Someone mentioning 14 gauge.
54	00:13:15*50 a	The patient's regurgitation sound audible.
55	00:13:15*50 a	Nurse is about to insert the suction tube.
56	00:13:16*80 a	The patient starts vomiting.
57	00:13:16*80 a	Nurse attempts to aim the suctioning tube.
58	00:13:22*83 a	Nurse suctioning the patient's vomits
59	00:13:32*77 a	Anesthesiologist looks over at the patient'
60	00:13:32*77 s	anesthesiologist picks up a syringe.
61	00:13:32*77 a	CRNA manipulates the ETT tube,
62	00:13:37*93 a	stimulating the patient, while the nurse is suctioning the airway.
63	00:13:51*50 a	The emergency medicine fellow, CRNA, and the surgeon is restraining the patient while he is vomiting.
64	00:13:54*17 a	anesthesiologist picks up some drugs (some more sux) from the drug shelf and draws up to the syringe.
65	00:13:57*47 a	while drawing up the sux, anesthesiologist looks over to the patient.
66	00:13:57*93 a	CRNA tells nurse to stop suctioning.
67	00:14:01*37 a	CRNA picks up larygoscope.
68	00:14:06*63 a	anesthesiologist inject the sux into iv.
69	00:14:14*53 a	CRNA withdraws the nasal tube out.
70	00:14:14*77 a	The anesthesiologist pulls out a line and passes to the surgical team.

Figure III.2. Transcriptions of the commentaries by the attending anesthesiologist who participated in the care in the example case (continued - p.2 of 3).

71	00:14:19*13 a	CRNA suctioning again the airway
72	00:14:20*57 a	The nurse is preparing another ETT tube.
73	00:14:26*97 a	The patient is pulling the suctioning tube.
74	00:14:33*83 a	CRNA is fighting with the patient
75	00:14:33*83 a	the patient is pushing CRNA away.
76	00:14:37*10 a	the nurse fits the ETT with guiding stylus.
77	00:14:46*43 a	CRNA instructs the nurse to get a "fat boy cuff", but the nurse does not understand, as he is showing off the ETT he just prepares.
78	00:15:05*40 a	Patient waves his hand.
79	00:15:06*90 a	anesthesiologist examines the iv access
80	00:15:07*13 a	anesthesiologist moves quickly to find sux syringes. (He bumps his head against the light).
81	00:15:09*87 a	CRNA starts to bag the patient.
82	00:15:14*13 a	anesthesiologist inject sux.
83	00:15:21*97 a	anesthesiologist finishes injection and makes sure the iv flow is adequate.
84	00:15:33*53 a	CRNA said "It's not fat boy cuff"
85	00:15:35*73 a	The nurse gives the ETT he prepared, probably to test if that tube is the so-called 'fat boy' cuff. CRNA said it is NOT the fat boy cuff.
86	00:15:42*97 a	CRNA is concentrating bagging the patient while looking at the patient.
87	00:15:58*63 a	CRNA is bagging the patient. He has the suction in one hand, laryngoscope in the other.
88	00:16:16*80 a	the nurse seems to grab another (blad?)
89	00:16:30*80 a	The emergency medicine fellow has the tying rope ready.
90	00:16:52*80 a	Someone comes in and put on a litre of fluid up.
91	00:17:06*43 a	CRNA is examine the patient's status while bagging the patient.
92	00:17:10*97 a	CRNA stops bagging and starts suctioning.
93	00:17:16*67 a	CRNA stops suctioning.
94	00:17:16*67 a	the anesthesiologist putting on the cricoid pressure and helps positioning the head.
95	00:17:19*97 a	The nurse picks up the following suction tube and put beside the patient. He has on one hand the ETT, the other the pilot line sealing syringe.
96	00:17:21*83 a	CRNA does laryngoscopy.
97	00:17:28*37 a	CRNA succeeds in laryngoscopy and indicates for ETT
98	00:17:28*37 a	the nurse passes the ETT to CRNA.
99	00:17:30*80 a	CRNA holds up the ETT, indicating the nurse to pull up the guiding stylus.
100	00:17:32*61 a	The nurse pulls up the stylus.
101	00:17:36*00 a	CRNA inserts the ETT.
102	00:17:38*13 a	the nurse pulls up the guiding stylus, and pass the pilot line syringe.
103	00:17:38*13 a	CRNA seals the ETT by pushing the pilot line sealing syringe.
104	00:17:44*13 a	CRNA connects the hand bag to ETT and starts to maunal ventilation.
105	00:17:53*87 a	emergency medicine fellow is auscaltating the patient, and reporting the results.
106	00:18:08*13 a	The nurse is passing the ETCO2 monitor to the CrNa.
107	00:18:17*43 a	The CRNA is tying up the ETT tube.
108	00:18:33*47 a	The nurse is adjusting ventilator.
109	00:18:48*33 a	.
110	00:18:48*33 a	Finishing annotation.
111	00:18:48.33 end	.

Figure III.2. Transcriptions of the commentaries by the attending anesthesiologist who participated in the care in the example case (continued - p.3 of 3).

OCS DATASET REPORT

DATASET FILE: 41B2.DAT

DESCRIPTION: sme (Dr. XXXX) sr & comments

OUTPUT FILE: 41B2.OCS

@

RECORD TIME CODE DESCRIPTION

RECORD	TIME	CODE	DESCRIPTION
1	00:00:00.00	start	.
2	00:00:05.00	mc	
3	00:00:05.03	mc	
4	00:00:05.07	mc	
5	00:00:05.10	mc	smeb2c - (Dr. XXXX) 10/20/92
6	00:00:05.13	mc	sr2 - (Dr. XXXX)
7	00:00:05.17	mc	
8	00:00:05.20	mc	[sme(b2) Pass Begins :00:10:50.00]
9	00:00:05.23	mc	[sme(b2) Pass Stops :00:44:29.07]
10	00:00:05.27	mc	
11	00:00:05.30	mc	
12	00:00:05.33	mc	
13	00:10:50.00	BEGIN.....	(sme(b2) pass begins @ patients arrival)
14	00:10:50.03	smeb2c	Arrival of the patient in the A.A. and the transfer of patient from gurney to the bed.
15	00:11:10.00	smeb2c	It looks like the patient is unconscious and not communicating.
16	00:11:21.00	smeb2c	There seems to be more activity than usual by the team.
17	00:11:30.00	smeb2c	C1 (John XXXX), is bagging the patient, trying to maintain the airway. Obviously the patient not taking any spontaneous respirations and if that's the case, suppose C1 will intubate soon.
18	00:11:53.00	smeb2c	The patient is not letting C1 stick the laryngoscope in his mouth. There is a H.R. of 114.
19	00:12:04.00	smeb2c	It looks as if C1 needs some help.
20	00:12:28.90	smeb2c	I.V. is now situated.
21	00:12:43.00	smeb2c	C1 attempting a blind, nasal intubation and patient is responding to that by the sound of things.
22	00:13:09.00	smeb2c	The patient is vomiting; obviously the passage of nasal tube is creating quite an alarming gag reflex.
23	00:13:23.00	smeb2c	The patient is still vomiting and the nasal tube is still halfway down the nose which may be continuing the stimulation. No attempt to get this patient into a position that they could logroll onto the side.
24	00:13:24.00	smeb2c	SME Forrest: "I find this a little bit strange."
25	00:14:10.00	smeb2c	H.R. of 145. Sounds like they've got a Cortis and they've got cpi on the way but SME Forrest is still not sure what the blood pressure is doing. Patient is actually responding at this stage.
26	00:14:24.00	smeb2c	A1 (Dr. Parr) has arrived on the scene.
27	00:14:56.10	smeb2c	Patient responding by grabbing at tubes.
28	00:15:05.00	smeb2c	Can't see how C1 has got the oxygen connected up, whether it's by nasal tube that's halfway down or whether it's actually bagging the patient still or just placing a mask over the patient's face - it's not clear.
29	00:16:00.00	smeb2c	It looks like they're going for formal intubation here.
30	00:16:01.00	smeb2c	It's difficult to tell what the motivation is, actually. It's not clear at all from the communication where they

Figure III.3: Transcriptions of the commentaries by an anesthesiologist who did not participate in the care in the example case

			are going. Not much verbalizing like, "Let's intubate" but presuming that they are still trying to secure the airway.
31	00:16:03.03	srb215	.
32	00:16:03.07	srb222	.
33	00:16:03.10	srb232	.
34	00:16:03.13	srb245	.
35	00:16:03.17	srb255	.
36	00:16:03.20	srb264	.
37	00:16:12.90	smeb2c	Bagging the patient: can't see what Al is doing but think that they must be going for a formal intubation having anesthetized the patient.
38	00:16:43.00	smeb2c	Michael, from OR night staff, has come in to hang a bag. Unusual for OR member to get involved in the resuscitation unless things are particularly dire. He's probably come to find out the extent of the problem with the patient.
39	00:17:10.67	smeb2c	Straightforward intubation: Al (Parr) is asking one of the team to listen to check breath sounds.
40	00:17:42.10	smeb2c	Ventilator is alarming.
41	00:18:02.00	smeb2c	Still no pressure, calling for o-pos. blood, and working diagnosis is severe hemorrhage from gunshot wound.
42	00:18:40.83	smeb2c	Blood has just arrived and they're going to give blood through the level one.
43	00:19:51.23	smeb2c	Al has now turned his attention to sorting out the fluid management now that the airway is secured. Cl has insured that tube is securely in place, the ventilator is sorted out, and has some drug in hand to give to patient.
44	00:20:10.57	smeb2c	H.R. is 138, still no sign of blood pressure.
45	00:20:55.00	smeb2c	It's difficult to know what lines they actually have established at this stage. [Can't really see much of what's been done because of the poor camera angle which completely blocks out the patient.]
46	00:21:27.03	srb214	.
47	00:21:27.07	srb223	.
48	00:21:27.10	srb233	.
49	00:21:27.13	srb245	.
50	00:21:27.17	srb255	.
51	00:21:27.20	srb264	.
52	00:21:59.30	smeb2c	They're still worried about left chest, there's muttering about chest tubes. Parr is now listening again and changing vent settings.
53	00:22:27.03	smeb2c	Patient's h.r. is down to 133, presumably in response to fluid-loading plus the fact that he's now unconscious from anesthesia.
54	00:22:45.00	smeb2c	Parr completing full monitoring to see what patient's temperature is.
55	00:22:51.23	smeb2c	The team is still talking about putting a test tube in and it's surprising that they haven't got it in yet if they wanted it.
56	00:23:12.73	smeb2c	At the moment, the level one is being managed by Michael (one of the O.R. staff) still. Difficult to say who, out of the team, is actually looking after the total volume of fluid going into the patient.
57	00:23:23.00	smeb2c	Al is talking about brachial arteries now. presumably for arterial line that the team will get ready to put in because he's severely hypotensive.

Figure III.3. Transcriptions of the commentaries by an anesthesiologist who did not participate in the care in the example case (continued - p.2 of 4).

58	00:23:50.13	smeb2c	Temp. of 36 shows up on data strip.
59	00:24:10.00	smeb2c	He's (A1?) going to follow the blood up with (crystyloid) presumably until he knows a bit more about the injury.
60	00:25:48.00	smeb2c	B.P. of 110/18 moving to 83/44.
61	00:26:25.00	smeb2c	There seems to be less urgency about the situation though still unclear about what's going on in the chest or the abdomen.
62	00:26:28.03	sr2213	.
63	00:26:28.07	sr2223	.
64	00:26:28.10	sr2233	.
65	00:26:28.13	sr2244	.
66	00:26:28.17	sr2254	.
67	00:26:28.20	sr2264	.
68	00:27:24.00	smeb2c	Mennen monitor alarming.
69	00:27:49.61	smeb2c	Presume that patient is breathing now because Parr is listening to patient's heart.
70	00:28:30.00	smeb2c	Team fellow is now going to attempt superior cordis; trauma line is going in.
71	00:28:39.10	smeb2c	Still haven't put chest tube in.
72	00:29:01.47	smeb2c	They haven't got any films. It's difficult to know what they've been doing at the lower end that's prevented them from putting in the chest tube and the superior cordis for quite a length of time.
73	00:29:05.00	smeb2c	There's been some talk about an arterial line and whether they've been concentrating their efforts on that, because it's difficult to get a blood pressure, I don't know.
74	00:29:41.83	smeb2c	Clinically, things have improved a bit for the patient since he's been admitted: B.P. is looking fairly respectable, H.R. is coming down, and temp. is normal.
75	00:32:38.30	smeb2c	Some problem with the groin line?
76	00:33:02.03	sr2213	.
77	00:33:02.07	sr2223	.
78	00:33:02.10	sr2233	.
79	00:33:02.13	sr2244	.
80	00:33:02.17	sr2254	.
81	00:33:02.20	sr2264	.
82	00:33:12.73	smeb2c	Manuevering for x-rays.
83	00:33:26.33	smeb2c	XXXX(C1) directing cpi.
84	00:33:53.10	smeb2c	XXXX(A1) ordering blood ahead; the whole team realizes that this man is going to require surgical intervention so they're going to be gearing up towards future resuscitation.
85	00:34:26.40	smeb2c	No mention by team of their plans, probably because they're still not sure what the extent of the injury is.
86	00:35:05.00	smeb2c	Clinically, things are in status quo: B.P. "not doing too badly," H.R. at 122.
87	00:36:09.77	smeb2c	Pulse oxymeter alarm, probably because of x-rays being taken.
88	00:41:14.47	smeb2c	X-ray personnel seem to have left.
89	00:42:07.07	smeb2c	Vital signs are reasonably stable.
90	00:43:00.47	smeb2c	Immediate request to go to O.R.; not great communication. Still don't know if they placed a chest tube.
91	00:44:29.03	sr2214	Transfer to O.R., period of instability, quite stressful because you have to get lines safely from one place to another and you tend to limit your monitoring.
92	00:44:29.07	sr2223	.
93	00:44:29.10	sr2233	.

Figure III.3. Transcriptions of the commentaries by an anesthesiologist who did not participate in the care in the example case (continued - p.3 of 4).

```
94    00:44:29.13 srb245      .  
95    00:44:29.17 srb255      .  
96    00:44:29.20 srb264      .  
97    00:44:29.23 STOP..... {sme(b2) pass stops @ end of case}  
98    10:00:00.00 end          .
```

Figure III.3. Transcriptions of the commentaries by an anesthesiologist who did not participate in the care in the example case (continued - p.4 of 4).

Figure III.4: Patient admission record for the example case

University of Maryland Medical Systems ANESTHESIA INTRA-OP RECORD									
Operating Room # <u>V1800</u>		Machine # <u>2500</u>		DATE <u>5-25-88</u>		ASA STATUS <u>X</u>		Allergies <u>None</u>	
<input type="checkbox"/> Gen <input type="checkbox"/> Reg <input type="checkbox"/> IV Sed		Patient <u>1</u>		Machine <u>1</u>		MD			
<input type="checkbox"/> Loc <input type="checkbox"/> MAC <input type="checkbox"/> Other		Identity Confirmed		Check Complete		Signed Consent			
CRNA/MD <u>1</u>		Anesthesia Start Time <u>2:30</u>		OR Start Time		OR End Time		PACU Anesthesia End Time <u>0:15</u>	
Surgeons <u>1</u>		Procedure Start Time		Procedure End Time		End Time <u>0:15</u>			
Diagnosis <u>GSW to ABD</u>									
Procedure(s) <u>CPR, LMP</u>									
Pre-Op Transport <input type="checkbox"/> Ambul <input type="checkbox"/> Other <input type="checkbox"/> Trach <input type="checkbox"/> Other <input type="checkbox"/> Cardiac Monitor <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Invasive Monitoring <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> PA <input type="checkbox"/> CVP <input type="checkbox"/> Art									
Intra-Op <input type="checkbox"/> Anesth <input type="checkbox"/> Other <input type="checkbox"/> Airway <input type="checkbox"/> Natural <input type="checkbox"/> Nasal <input type="checkbox"/> Oral <input type="checkbox"/> Other <input type="checkbox"/> Eit size <input type="checkbox"/> Nasal <input type="checkbox"/> Trach <input type="checkbox"/> Other <input type="checkbox"/> Scope/Fibero <input type="checkbox"/> Attempts <input type="checkbox"/> Position <input type="checkbox"/> Eyes Prot <input type="checkbox"/> Press. Pts <input type="checkbox"/> Position									
<input type="checkbox"/> EKG <input type="checkbox"/> Pk <input type="checkbox"/> FIO ₂ <input type="checkbox"/> CVP <input type="checkbox"/> A-line <input type="checkbox"/> Sat <input type="checkbox"/> ABP <input type="checkbox"/> PHS <input type="checkbox"/> ETCO ₂ <input type="checkbox"/> Foley cath <input type="checkbox"/> Temp <input type="checkbox"/> ICP <input type="checkbox"/> Steth P/E <input type="checkbox"/> EEG/EP									
<input type="checkbox"/> Heating <input type="checkbox"/> Blanket <input type="checkbox"/> Tourniquet <input type="checkbox"/> Humidity <input type="checkbox"/> Blood Warmer <input type="checkbox"/> Mech Vent <input type="checkbox"/> CP Bypass <input type="checkbox"/> Other									
Remarks: <u>1. Ind. O2 for AB by manual exp. by 2nd GSW to abd. Port to right</u> <u>2. Spine & Vent. AS P/O, C. No. 1. Section PA interlocking with</u> <u>RT. 3. Monitor O2, 4. O2, 5. O2, 6. O2, 7. O2, 8. O2, 9. O2, 10. O2</u> <u>Other: No other notes. All vital signs maintained. No adverse reactions. No complications.</u>									
PACU Invasive Monitoring <input type="checkbox"/> Yes <input type="checkbox"/> No									
BP <u>120/80</u> P <u>90</u> RR <u>12</u> PA S/O <u>120</u> PCWP <u>12</u> CVP <u>12</u>									
<input type="checkbox"/> Awake <input type="checkbox"/> Reactive <input type="checkbox"/> Asleep <input type="checkbox"/> Airway <input type="checkbox"/> Natural <input type="checkbox"/> Trach <input type="checkbox"/> Oral <input type="checkbox"/> Nasal <input type="checkbox"/> ICP									
FIO ₂ <u>1.0</u> Vi <u>10</u> Peep <u>5</u> R <u>12</u> <input type="checkbox"/> EKG <input type="checkbox"/> Art <input type="checkbox"/> PA <input type="checkbox"/> SaO ₂ <u>98</u>									
Aldrete Score <u>10</u> Report Given <input type="checkbox"/> Yes <input type="checkbox"/> No									
Post Surgical Transport Location: <u>ICU</u>									
Ventilator <input type="checkbox"/> Yes <input type="checkbox"/> No									
Sup. O ₂ <input type="checkbox"/> Yes <input type="checkbox"/> No									
<input type="checkbox"/> SaO ₂ <input type="checkbox"/> EKG									
Q/A COORDINATOR <u>1</u>									

Figure III.5: Intraoperative anesthesia record for the example case

Figure III.5. Intraoperative anesthesia record for the example case (continued - p.2 of 2).

Figure III.5. Intraoperative anesthesia record for the example case (continued - p.2 of 2).

#41

MIEMSS #	DOE, J	History #	Page 1
<u>FiO2 %</u>			
	08/27/92 22:20	100	
	08/27/92 22:45	100	
	08/27/92 23:15	100	
	08/28/92 00:00	100	
	08/28/92 01:00	100	
<u>Set PEEP (cm H2O)</u>			
	08/27/92 22:45	4	
	08/27/92 23:15	10	
	08/28/92 00:00	8	
	08/28/92 01:00	8	
<u>PaO2 (80-100 mmHg)</u>			
	08/27/92 22:20	254	
	08/27/92 22:45	96	
	08/27/92 23:15	329	
	08/28/92 00:00	365	
	08/28/92 01:00	399	
<u>pH (art) (7.35-7.45)</u>			
	08/27/92 22:20	6.83	
	08/27/92 22:45	7.11	
	08/27/92 23:15	7.35	
	08/28/92 00:00	7.16	
	08/28/92 01:00	7.07	
<u>PaCO2 (35-45 mmHg)</u>			
	08/27/92 22:20	63	
	08/27/92 22:45	37	
	08/27/92 23:15	21	
	08/28/92 00:00	21	
	08/28/92 01:00	30	
<u>O2sat (art) (95-99%)</u>			
	08/27/92 22:20	99.0	
	08/27/92 22:45	94.0	
	08/27/92 23:15	99.0	
	08/28/92 00:00	99.0	
	08/28/92 01:00	99.0	
<u>Base Ex (0+-2 mmol/L)</u>			
	08/27/92 22:20	-23.6	

Figure III.6: Laboratory analysis, hematology, and biochemistry data for the example case

MIEMSS #	DOE, J	History #	Page
08/27/92 22:45	-16.2		
08/27/92 23:15	-11.0		
08/28/92 00:00	-18.7		
08/28/92 01:00	-19.5		
<u>HCG3- (22-26 mmol/L)</u>			
08/27/92 22:20	10.6		
08/27/92 22:45	11.9		
08/27/92 23:15	11.5		
08/28/92 00:00	7.4		
08/28/92 01:00	8.8		
<u>Hgb (12-15 g/dL)</u>			
08/27/92 22:05	6.7		
08/27/92 23:15	4.7		
08/28/92 00:00	6.8		
08/28/92 01:00	4.4		
<u>Hct (35-50%)</u>			
08/27/92 22:05	22.0		
08/27/92 23:15	14.9		
08/28/92 00:00	21.0		
08/28/92 01:00	14.1		
<u>WBC (5000-10,000/mm³)</u>			
08/27/92 22:05	3200		
08/27/92 23:15	5100		
08/28/92 00:00 *	3700		
08/28/92 01:00 *	2300		
* Abnormal cells detected. Blood smear exam suggested.			
<u>Plat (150-400x10³/mm³)</u>			
08/27/92 22:05	122		
08/27/92 23:15	61		
08/28/92 00:00 #	29		
08/28/92 01:00 #	62		
# Abnormal platelets present. Confirming platelet count & smear indicate			
<u>RBC (4.0-6.0x10⁶/mm³)</u>			
08/27/92 22:05	2.87		
08/27/92 23:15	1.75		

Figure III.6. Laboratory analysis, hematology, and biochemistry data for the example case (continued - p.2 of 6).

MIEMSS #	DDE, J	History #	Page 3
08/28/92 00:00	2.47		
08/28/92 01:00	1.57		
<u>MCV (85-95fL)</u>			
08/27/92 22:05	77		
08/27/92 23:15	85		
08/28/92 00:00	85		
08/28/92 01:00	90		
<u>PT(pat)(cont +/-1sec)</u>			
08/27/92 22:05	15.9		
08/27/92 23:15	30.0		
08/28/92 00:00	24.6		
<u>P.T. (control)(secs)</u>			
08/27/92 22:05	12.4		
08/27/92 23:15	12.4		
08/28/92 00:00	12.4		
<u>PTT(pat)(cont +/-5sec)</u>			
08/27/92 22:05	86.9		
08/27/92 23:15	180.0		
08/28/92 00:00	180.0		
<u>Fibr (150-400mg/dL)</u>			
08/27/92 22:05	136		
08/27/92 23:15	41		
08/28/92 00:00	57		
<u>+ (135-148 mEq/L)</u>			
08/27/92 22:05	150		
08/27/92 23:15	140		
08/28/92 01:00	146		
<u>K+ (3.6-5.0 mEq/L)</u>			
08/27/92 22:05	4.8		
08/27/92 23:15	5.6		
08/28/92 01:00	6.4		
<u>Cl- (98-108 mEq/L)</u>			
08/27/92 22:05	110		

Figure III.6. Laboratory analysis, hematology, and biochemistry data for the example case (continued - p.3 of 6).

MIEMSS #	DOE, J	History #	Page
08/27/92 23:15		105	
08/28/92 01:00		110	
<u>CO2 (22-29 mEq/L)</u>			
08/27/92 22:05		15.7	
08/27/92 23:15		10.2	
08/28/92 01:00		9.4	
<u>Glu (70-110 mg/dL)</u>			
08/27/92 22:05		183	
08/27/92 23:15		232	
08/28/92 01:00		213	
<u>Urea Nit(6-20 mg/dL)</u>			
08/27/92 22:05		8	
08/27/92 23:15		7	
08/28/92 01:00		6	
<u>Creat(0.5-1.2 mg/dL)</u>			
08/27/92 22:05		1.8	
08/27/92 23:15		1.9	
08/28/92 01:00		1.2	
<u>Ca, tl(8.5-10.5mg/dL)</u>			
08/27/92 22:05		7.3	
08/27/92 23:15		4.4	
08/28/92 01:00		4.2	
<u>Osmo (275-295 mOsm)</u>			
08/27/92 22:05		319	
08/27/92 23:15		299	
08/28/92 01:00		304	
<u>P, T, T. (cont.)(secs)</u>			
08/27/92 22:05		25.9	
08/27/92 23:15		26.2	
08/28/92 00:00		26.2	
<u>Phosph(2.5-4.5mg/dL)</u>			
08/27/92 22:05		11.4	
<u>Bil tot(2-1.0mg/dL)</u>			
08/27/92 22:05		0.4	

Figure III.6. Laboratory analysis, hematology, and biochemistry data for the example case (continued - p.4 of 6).

MIEMSS #	DOE, J	History #	Page 5
<hr/>			
AST/SGOT (10-42 U/L)			
08/27/92 22:05	58.		
<hr/>			
Alk Phos (20-120 U/L)			
08/27/92 22:05	34.		
<hr/>			
Mg+ (1.3-2.5 mEq/L)			
08/27/92 22:05	2.6		
<hr/>			
Amylase (25-125 U/L)			
08/27/92 22:05	89		
<hr/>			
ct (0.5-2.2 mmol/L)			
08/27/92 22:05	14.4		

Figure III.6. Laboratory analysis, hematology, and biochemistry data for the example case (continued - p.5 of 6).

MIEMSS #	DOE, J	History #	Page 6
MIEMSS Physical Therapy Treatments			
Procedure	Response	Therapist	License #
PTE = Physical Therapy Evaluation GE = General Evaluation ADL = Activities of Daily Living AF = Appliance Fabrication RP = Routine Program CPT = Chest Physical Therapy PTP = Physical Therapy Procedure F = Favorable U = Unfavorable			
r additional information, call 328-7667.			

Figure III.6. Laboratory analysis, hematology, and biochemistry data for the example case (continued - p.6 of 6).

Betadine from the chin to the mid-thighs. A midline incision was made and massive hemoperitoneum was encountered and he was packed in all quadrants and the greatest amount of bleeding seemed to be coming from the center of his mesentery and this was packed off. We did occlude the aorta under the diaphragm using manual compression on the aorta. There was bleeding from the small bowel mesentery which was arterial type bleeding and this was oversewn using 4-0 Prolene sutures. We then inspected the left lower quadrant and left upper quadrant areas and there was no bleeding noted from this area and there was no bleeding around the liver and then we turned our attention to the central hematoma and active bleeding which seemed to be coming from the inferior vena cava or iliac veins. Using sponges we tried to control the bleeding and the peritoneum was excised and the vena cava was identified and we were able to see the right ureter and it was intact and kept out of the field. The iliac artery was identified and isolated with vessel loops. There was a massive amount of bleeding which was quite difficult to control.

We passed a Fogarty catheter from the saphenous vein cutdown that we had done to try to get the bleeding down but this did not help and we then passed Foley catheter through the hole that we identified at the inferior vena cava just at the bifurcation to try to occlude the proximal vena cava and also inserted the balloon into the right iliac system and this helped control the bleeding somewhat.

We then controlled the inferior vena cava and ligated it proximal and distal to the hole using an 0 silk suture. There was still a fair amount of bleeding noted probably from some lumbar which was quite difficult to control. We tried packing while anesthesia tried to catch up. At this point he had received over forty units of packed cells and multiple units of fresh frozen plasma and IV fluids.

We also encountered numerous enterotomies so we tried to maintain pressure of the bleeding at the cava and we oversewed the small bowel enterotomies using 3-0 silk sutures. There was one area where the small bowel was pretty much devitalized and this was divided using a GIA stapler and the mesentery which was bleeding was oversewn using a 3-0 Prolene suture.

The colonic injury was also noted and was oversewn using 3-0 silk. There were approximately eight small bowel holes which were closed. We then tried to gain control of the bleeding down to the iliacs again but we were unable to do so. The patient experienced significant coagulopathy. At this point we instructed the anesthesia department to stop giving the massive transfusions to see if the patient could maintain a blood pressure on his own and we started to close the abdomen. Unfortunately the patient was unable to maintain his blood pressure and was pronounced dead at 1:30 am.

Figure III.7. Operative and discharge summary for the example case (continued - p.2 of 4).

STRG CASE # 41

OPERATIVE REPORT

MIEMSS #:

HOSPITAL #:

DATE OF PROCEDURE:

SERVICE:

GENERAL

ATTENDING:

M.D.

FELLOW/RESIDENT:

, M.D.

ANESTHESIOLOGIST:

M.D.

NURSE ANESTHETIST:

, C.R.N.A.

ANESTHESIA:

GENERAL ENDOTRACHEAL

PREOPERATIVE DIAGNOSIS:

GUNSHOT WOUND TO THE ABDOMEN.

POSTOPERATIVE DIAGNOSIS:

SAME WITH INFERIOR VENA CAVAL
INJURY, SMALL BOWEL MESENTERY
INJURY, NUMEROUS SMALL BOWEL
ENTEROTOMIES AND COLONIC
ENTEROTOMY.

OPERATION:

EXPLORATORY LAPAROTOMY; LIGATION OF
INFERIOR VENA CAVA; LIGATION OF
MESENTERIC ARTERIAL BLEEDERS;
OVERSEW OF SMALL BOWEL
ENTEROTOMIES; OVERSEW OF COLONIC
ENTEROTOMY; DIVISION OF SMALL BOWEL
USING GIA STAPLER.

ESTIMATED BLOOD LOSS:

BLOOD REPLACED:

DRAINS:

COMPLICATIONS:

INDICATION FOR SURGERY: The patient is a John Doe brought in from the scene in extremis with a single gunshot wound to the right upper quadrant. Cutdowns were done to the groins in the admitting area for a large-bore IV access as well as a subclavian line in his right thigh and a left chest tube was placed as well. He was resuscitated in the admitting area and x-rays were done which showed this bullet to cross the midline and descend posteriorly in the right lower quadrant. We did get his pressure back to the 100s but his belly was massively distended and he was emergently taken to the operating room.

PROCEDURE: The patient was taken to the operating room and placed on the operating room table in the supine position. After adequate anesthesia was obtained, the patient was prepped with

Figure III.7: Operative and discharge summary for the example case

The medical examiner was called. The patient's abdomen was closed with running #1 PDS and #2 nylon sutures. His midline incision and groin incisions were closed using 3-0 nylon. Before ligating the inferior vena cava both Foley balloons were removed.

DICTATED FOR
 , M.D.

DICTATED BY
 , M.D.

SUMMARY:

This 30s-appearing obese black male was brought by ambulance from the scene with a single gunshot wound to the abdomen. Vital signs in the field were blood pressure 100/palpable, pulse 128, and respirations in the 30s and shallow. Upon consult, field personnel described decreased left breath sounds and stated there was a gunshot wound to the left chest. He arrived on a backboard, restrained, disoriented, and combative. Upon arrival to the trauma bay, he became limp and unresponsive. Initial blood pressure was 98/65, heart rate 140 monitored, and respirations became agonal. The patient was emergently intubated, and breath sounds were decreased on the left; therefore, a #14-gauge Angiocath was placed into the left second intercostal space to avert a possible tension pneumothorax. Meanwhile, bilateral saphenous cutdowns were conducted, and 8.5 sheath introducers were placed in the saphenofemoral junction. A #36 French thoracostomy tube was then placed in the left fifth intercostal space at the anterior axillary line, and x-rays were obtained. The abdominal flat plate revealed a missile, relatively small caliber, in the right iliac fossa, an entry wound having been in the left upper quadrant. Massive fluid resuscitation was initiated, with the vital signs showing equivocal response. The patient's abdomen, already obese, became increasingly distended and tense. Four units of uncrossmatched blood were given immediately, and three liters of Plasma-Lyte was infused via the rapid high-pressure infuser. Chest x-ray revealed all tubes to be in good position, and the patient was emergently taken to the operating room for laparotomy. He was explored and found to have through-and-through wounds of the distal inferior vena cava at the confluence of common iliac veins. There was also a through-and-through wound of the right iliac vein as well. The patient was coagulopathic initially upon arrival to the Trauma Resuscitation Unit with an initial PTT of 86.4 seconds. Intraoperatively, he became profoundly coagulopathic, having massive transfusion of 40+ units packed red blood cells, 20+ units of fresh frozen plasma, and 30+ units of platelets. Despite all attempts at control of his major hemorrhage, he only became increasingly coagulopathic and hypotensive in spite of multiple pressors. He, at last, was unable to maintain a blood pressure and succumbed to an exsanguinating hemorrhage complicated by profound coagulopathy. He was declared dead at 1:30 a.m. on 08/28/92.

This patient's past medical history was unknown to us as well as past surgical history, medications, and allergies. His physical

Figure III.7. Operative and discharge summary for the example case (continued - p.3 of 4).

examination was as listed above. Laboratory findings initially were of postintubation arterial blood gas of pH 6.83, pCO₂ 63, pO₂ 254, and 99 percent saturation. CBC revealed white blood cell count of 3,200, hemoglobin 6.7, hematocrit 22, and platelets 122,000. PT was 15.9 seconds, PTT 86.9 seconds. To reiterate, these were initial values from which he became increasingly coagulopathic. X-ray examination consisted of supine chest and abdomen and lateral abdomen, the chest revealing no pneumothorax and no hemothorax, and the abdomen revealing no pneumoperitoneum but a missile which had traversed the midline, coming to lie in the right iliac fossa.

The medical examiner was notified postmortem, and the body will be transported to the morgue and from there the medical examiner's office for autopsy. As of this dictation, the patient's identity remains unknown, and no family or friends have presented to inquire about the patient.

Dictated for _____
_____, M.D.

Dictated by _____
_____, M.D.

Figure III.7. Operative and discharge summary for the example case (continued - p.4 of 4).

Figure III.8. Fluid infusion records for the example case (continued - p.2 of 3).

University of Maryland Medical Systems
MIEMSS / STCC **RIS DATA FORM**

START TIME: 2230 END TIME: 0135 DATE: [blank]
 SURGICAL ATTENDING: [blank]
 ANES. PROVIDER: [blank]
 PERFUSIONIST (NAME / SIGNATURE): [blank] CO# 0613

FAA: [blank]
 DR. [blank]
 MIEMSS #01 [blank]

TIME	2230	2235	2245	2300	2302	2304	2310	2317	2322
PRBC	0	0	0	0	0	0	0	0	0
FFP	0	0	0	0	0	0	0	0	0
PLVT	0	0	0	0	0	0	0	0	0
NaCl	0	0	0	0	0	0	0	0	0
FLOW RATE	37	39	39	38	37	37	37	37	37
TEMP	37	39	39	38	37	37	37	37	37
PRESS	60	62	60	58	56	56	56	56	56
VOL INFUSED	112	136	113	94	114	114	114	114	114

TIME	2322	2340	2345	0000	0015	0030	0045	0100	0115
PRBC	300	600	180	500	180	180	180	180	180
FFP	0	0	0	0	0	0	0	0	0
PLVT	100	100	100	100	100	100	100	100	100
NaCl	0	0	0	0	0	0	0	0	0
FLOW RATE	37	39	39	38	37	37	37	37	37
TEMP	37	39	39	38	37	37	37	37	37
PRESS	60	62	60	58	56	56	56	56	56
VOL INFUSED	112	136	113	94	114	114	114	114	114

BOLUS

TIME	2234	2236	2247	2249	2256	2301	2303	2309	2317
AMOUNT	500	500	500	500	500	500	500	500	500
TIME	2234	2236	2247	2249	2256	2301	2303	2309	2317
AMOUNT	500	500	500	500	500	500	500	500	500

HOURLY TOTALS: INFUSION & BOLUS					BLOOD PRODUCTS USED		
TOTAL	5319	15576	42571	53523	53 G 6/195	53 G 6/195	1202237
TIME	1305	2405	0105	0130	53 K 9/111	53 K 9/111	1202237
					53 T 7/367	53 T 7/367	1202237
					53 J 1/113	53 J 1/113	1202237
					53 L 1/113	53 L 1/113	1202237
					53 K 9/111	53 K 9/111	1202237
					53 G 6/195	53 G 6/195	1202237
					53 L 1/113	53 L 1/113	1202237
					53 K 9/111	53 K 9/111	1202237
					53 L 1/113	53 L 1/113	1202237

TYPE / SIZE CATHETER	VENOUS CATHETER LOC
#1 7/8 PL	LEFT SUBCLAVIAN
#2	

COMMENTS: [blank] **ALARMS:** [blank]

FLUID REMAINING IN RESERVOIR: [blank] HOW DISPOSED: [blank] ATTENDING SIGNATURE: [blank]

FORM # 50285 (REV. 1/02)

Figure III.8: Fluid infusion records for the example case

University of Maryland Medical Systems MIEMSS / STCC RIS DATA FORM										TAA TRA DR. MIEMSS DOE			
START TIME 2205		END TIME 2230		DATE									
SURGICAL ATTENDING													
ANES. PROVIDER													
PERFUSIONIST (NAME / SIGNATURE) <i>[Signature]</i>													
DEP <i>[Signature]</i>													
TIME	2205		2220		2230								
PRBC	FFP	600		-		-							
PLVT	NaCl	2000		-		-							
FLOW RATE	TEMP	52.2 HR		50.1 HR		52.2 HR							
PRESS	VOL INFUSED	52		51		52							
TIME													
PRBC	FFP												
PLVT	NaCl												
FLOW RATE	TEMP												
PRESS	VOL INFUSED												
BOLUS													
TIME	2212		2217										
AMOUNT	500		500										
TIME													
AMOUNT													
HOURLY TOTALS: INFUSION & BOLUS						BLOOD PRODUCTS USED							
TOTAL	1160								53.64		40.15		
TIME	2230								53.64		10.79		
TYPE / SIZE CATHETER				VENOUS CATHETER LOC									
#1 7/8 FL				L-17 ST-1000									
#2													
COMMENTS:						ALARMS:							
FLUID REMAINING IN RESEVOIR				HOW DISPOSED				ATTENDING SIGNATURE					

FORM # 50265 (REV. 1/92)

Figure III.8. Fluid infusion records for the example case (continued - p.3 of 3).

Appendix IV: Database Description

The database collected for the project contains a multitude of information:

1. Videotapes. The videotapes were recorded on a VHS tape, stamped with two types of timecode: VITC and LTC. Video images were overlaid with the patient's vital signs data. The videotapes of a small number of the cases were also overlaid with transcriptions of verbal communications and major events.
2. Audio review tapes. These audiotapes were made while the subject matter experts reviewed videotapes and/or were interviewed.
3. Stress ratings. These ratings were given at one-minute intervals by one or more subject matter experts.
4. Admitting chart. The chart used by the Shock Trauma Center to register the patient's basic demographic information (with patient's identification removed) and the results of initial consultation.
5. Anesthesia chart. The chart used by the attending anesthesiologists during anesthetics. It contained the drugs used, timing of events, and logs of the patient's vital signs.
6. Physiological data. These data were captured during care by directly interfacing with patient physiological monitors.
7. Discharge summary. The summary was written at the end of the care, either after the patient was stable enough to leave the shock trauma center, or the patient expired.
8. Intubation analysis. The Intubation Analysis Questionnaire is a form to collect critical information about the events and performance during intubation.
9. Transcription of video tapes. To facilitate analysis of verbal communications, a number of selected cases were transcribed.
10. Post Trauma Questionnaire. It was a questionnaire to be completed at the end of videotaping.

The table included here describes the types of data available for each of the cases videotaped.

Appendix V: List of Publications

During the period under the funding from the ONR grant, the PI and his colleagues have published a number of papers, abstracts, and book chapters. This appendix lists the publications. For other achievements with the funding, access the homepage of the Anesthesiology Research Laboratories on World Wide Web:

<http://www.anesthlab.ab.umd.edu>.

1992

Gerold KB, Dauphinee K, Mackenzie CF, and LOTAS. Hypotension in acutely traumatized patients. In *Decision-Making in Anesthesiology*. 2nd Edition, Eds Bready LL, Smith RB, BC Decker Co, Toronto pp 342-343; 1992.

1993

Craig GR, Forrest FC, Mackenzie CF, Parr MJ, Boehm C, Gorman G and LOTAS. Performance of trauma anesthesiologists assessed by a synthetic work environment. *J. Clin Monit* 9:228-229; 1993.

Mackenzie CF. Simulation of Trauma Anesthesia (includes notation of LOTAS group). In Grande, CM Ed. *Textbook of Trauma Anesthesia and Critical Care*. Chap 98 pp 1180-1191; 1993. Mosby Year Book, Inc. St. Louis.

Mackenzie CF, Craig GR, Parr MJ and LOTAS. Video analysis of two emergency tracheal intubations identifies errors in decision-making. *J. Clin Monit* 9:227-228; 1993.

Mackenzie CF, Horst RL, Mahaffey DL and LOTAS Group. Decision-making during trauma patient resuscitation and anesthesia. *Proc. Human Factor and Ergonomics. Soc. 37th Ann Meeting*, pp 372-376; 1993.

1994

Hunter A, Mackenzie CF, Jeffries N, Wesolowski J, Bernhard W. and LOTAS. Video-analysis of tasks performed during emergency, semi-emergency and elective intubation of trauma patients. *Anesthesiology* 81:A626; 1994.

Jeffries NJ Hunter A, Bernhard W, Mackenzie CF, Horst R. and LOTAS. Incidence of procedural errors and untoward occurrences associated with tracheal intubation assessed from video tapes and self-reports. *Anesthesiology* 81:A1211; 1994.

Mackenzie CF, Horst RL and LOTAS. Team communications reveal the root causes of performance problems observed in airway management of trauma patients. *Proc. of 12th Triennial Congress of the International Ergonomics Ass.* Vol 5, pp 65-67; 1994.

Mackenzie CF, Craig GR, Parr MJ, Horst R. and LOTAS. Video analysis of two emergency tracheal intubations identifies flawed decision-making. *Anesthesiology* 81:763-771; 1994.

Mackenzie CF and LOTAS. Simulation of trauma management: The LOTAS experience.

Eur. J. Emergencies 4:184-92; 1994.

1995

Harper B, Mackenzie CF, Norman KL. Quantitative measures in the ergonomic examination of the trauma resuscitation units anesthesia work space. Proc Human Factors and Ergonomic Soc 39th Annual Meeting, San Diego, Vol 2 pp 723-727;1995.

Jaberi M, Bernhard W, Xiao Y, Mackenzie CF, The LOTAS Group. Can we use videotaping to analyze experience in tracheal intubation. Anesthesiology 83:A1013;1995.

Mackenzie CF, Hunter A, Xiao Y, Bernhard W, The LOTAS Group. Task priorities and their omission before emergency and elective intubation. Anesthesiology 83:A216;1995.

Mackenzie CF, Harper BP, Norman KL, Jaberi M and LOTAS. Ergonomic examination of the anesthesia workstation by video analysis. Int. J. Clin Monit and Comput 12:181-182;1995.

Mackenzie CF, Hu PF-M, Horst RL and LOTAS. An audio-video acquisition system for automated data acquisition in the clinical environment. J Clin Monit. 11:335-41; 1995.

Mackenzie CF and LOTAS. Real videos for training. Care Crit Ill 11:227-229; 1995.

Xiao Y, Mackenzie CF, Bernhard W, The LOTAS Group. Identifying stressors during airway management through regression analysis. Anesthesiology 83:A1119;1995.

Xiao Y, Mackenzie CF, The LOTAS Group. Does stress induce more errors in airway management? Anesthesiology 83:A1118; 1995.

Xiao Y, Mackenzie CF and The LOTAS Group. Decision making the dynamic environments. Fixation errors and their causes. Proc Human Factors and Ergonomic Soc 39th Annual Meeting San Diego Vol 1 pp 469-473; 1995.

Xiao Y, Milgran P, Doyle DJ. Medical Case Rounds: A mechanism for training and studying real-life decision-making. Proc. Human Factors and Ergonomic Soc 39th Annual Meeting Vol 2 pp 1330-1333; 1995.

1996

Harper BD, Jaberi M, Mackenzie CF, and LOTAS. Increasing efficiency in the trauma resuscitation anesthesia workspace. Anesthesiology, 85(3A); 1996.

Jaberi M, Xiao Y, Mackenzie CF, and LOTAS. Incident monitoring by videotaping of acute trauma patient management. Anesthesiology, 85(3A):A1036; 1996.

Mackenzie CF, Martin P, Xiao Y and LOTAS. Video Analysis of Prolonged Uncorrected Esophageal Intubation. Anesthesiology, 84(6):1394-1503; 1996

Mackenzie CF, Jefferies NJ, Hunter A, Bernhard W, Xiao Y, Horst R, and the LOTAS Group. Comparison of self-reporting of deficiencies in airway management with video-analysis of actual performance. Human Factors, 38:623-635, December, 1996.

Mackenzie CF, Nolan J, Kahn R, Delaney P, Grande C, and the LOTAS Group. Trauma anesthesia practices, training, and facilities. Anesthesiology, 85(3A):A252; 1996.

Mackenzie CF, Harper B, and Xiao Y. Simulator limitations and their effects on decision-making. Proc. Human Factors and Ergonomics 40th Annual Meeting pp.747-751; 1996.

Mackenzie CF, Dutton R, Jaberi M, Harper B, Xiao Y, and LOTAS. Simulator limitations affect evaluation of performance. Anesthesiology, 85(3A):A268; 1996

Mackenzie CF, Nolan J, Kahn R, Delaney P, Grande C, and the LOTAS Group. Trauma anesthesia practices, training, and facilities. *Anesthesiology*, 85(3A):A252; 1996

Xiao Y, Mackenzie CF and The LOTAS Group. Remote diagnosis in dynamic task environments. *Proc Human Factors Soc 40th Ann Meeting Philadelphia Sept*, 1996.

Xiao Y, Hunter WA, Mackenzie CF, Jefferies NJ, Horst R, and the LOTAS Group. Task complexity in emergency medical care and its implications for team coordination. *Human Factors*, 38:636-645; 1996.

Xiao Y, Mackenzie CF, Jaber M, Harper B, and LOTAS. Alarms: Silenced, ignored, missed. *Anesthesiology*, 85(3A):A422; 1996

Xiao Y, Mackenzie CF, Bernhard W, Hebel JR, and LOTAS. Dynamics of stress during elective and emergency airway management. *Anesthesiology*, 85(3A):A957; 1996.

1997

Dutton RP, Xiao Y, Bernhard W, Boehm C, Gabbot D, Hunter A, Jaber M, Wesolowski J, Mackenzie CF and LOTAS. Measured versus predicted stress during elective and emergency airway management. *Anesthesiology*, 87(3A):A444; 1997

Xiao Y, Mackenzie CF, Ovelgone D and LOTAS. Simulator realism impacts diagnostic abilities on auscultation. *Anesthesiology*, 87(3A):A939; 1997.

Xiao Y, and Mackenzie CF. Uncertainty in trauma patient resuscitation. *Proc. Human Factors and Ergonomics 41th Annual Meeting*, 168-171; 1997

Xiao Y, Milgram P, and Doyle DJ. Capturing and modelling planning expertise in anesthesiology: Results of a field study. In C. Zsombok & G. Klein (Eds.): *Naturalistic Decision Making*, Mahwah, NJ:LEA, pp. 197-205; 1997

Xiao Y, Milgram P, Doyle DJ. Planning behavior and its functionalities in the interaction with complex systems. *IEEE Trans on Systems, Man and Cybernetics*. 27(3):313-324; 1997.

1998

Mackenzie CF, Xiao Y, Ovelgone D, and the LOTAS Group. Utilization of personnel during trauma patient resuscitation. *J. Clin. Monit.* In Press.

Mackenzie CF, Xiao Y, Jaber M, Ahmed S, Spencer R, Ovelgone D, and the LOTAS Group. Strengths and weaknesses of airway teleconsultation. *J. Clin. Monit.* In Press.

Xiao Y, Mackenzie CF, and the LOTAS Group. Do surgeons, nurses, and anesthesiologists perceive the same medical care differently? *J. Clin. Monit.* In Press.

Xiao Y, Mackenzie CF, Ovelgone D, and the LOTAS Group. Simulator realism impacts diagnostic abilities on auscultation. *J. Clin. Monit.* In Press.

Appendix VI: Glossary

ACP Anesthesia care provider, either an anesthesiologist and a nurse anesthetist.

ACLS Advanced Cardiac Life Support

ATLS Advanced Trauma Life Support

Airway Management includes maintaining a patent airway in conscious and unconscious patients by means of head tilt, jaw thrust, and tracheal intubation. In unconscious patients, the airway is protected against aspiration of regurgitated stomach contents (see below) by use of an inflatable cuff on the tracheal tube.

Anesthesia State of unconsciousness induced by intravenous or inhaled drugs.

Anesthesia Bag A 3L rubber bag included in the patient ventilating circuit that can be manually compressed to provide patient ventilation.

Anesthesia Record A written document that records patient vital signs, every 5 min, and documents the timing of anesthetic and surgical interventions and any drugs and fluids given. It describes any unusual patient responses or events.

Anesthesia Care Providers physicians (Attending or faculty, Fellow or Resident-in-Training) or nurses (Certified Registered Nurse Anesthetists).

Anesthesia Quality Assurance (AQA) A process of peer review designed to capture all occurrences, some of which result in harm or a poor outcome.

Aspiration Passage of regurgitated stomach contents into the trachea because laryngeal reflexes are obtunded due to anesthesia, muscle paralysis or unconsciousness.

Auscultate To listen to, using a stethoscope applied over the heart, lungs or abdomen.

CRNA Certified Registered Nurse Anesthetist.

Cricoid Pressure Digital pressure applied with thumb and index finger over the cricoid cartilage situated just below the larynx in the neck. This pressure prevents regurgitation of stomach contents when anesthesia is induced in emergency circumstances in patients with full stomachs.

Disconnect Alarm An auditory alarm that sounds when the ventilating circuit between the anesthesia machine or mechanical ventilator becomes disconnected from the patient's airway.

Elective Intubation The airway is electively intubated, usually with the patient adequately investigated and comprehensively monitored.

Emergency intubation In this study, defined as an intubation required within 10 min of the patient's arrival into the trauma center. Emergency intubations are considered more risky than elective intubation because less is known about the patient's status.

End-Tidal CO₂ (ETCO₂) The value of CO₂ concentration at the end of exhalation. ETCO₂ approximates the arterial CO₂. A value of ETCO₂ greater than 30 mmHg for 5 consecutive breaths confirms that the tracheal tube is in the trachea not the esophagus.

EOA Esophageal obturator airway

Esophageal Intubation The accidental passage of a tracheal tube into the esophagus. If undetected this will cause lack of oxygen in the circulation. Detection of esophageal intubation is made by auscultation of the chest and abdomen and a failure to detect ETCO₂ for 5 breaths.

Esophageal Obturator Airway (EOA) A device that can be used in unconscious patients to occlude the esophagus and prevent regurgitation of stomach contents. By application of a mask over the face the lungs are ventilated. A tracheal tube should be placed and its cuff inflated to prevent aspiration into the lungs before removal of EOA. The advantage of the EOA over tracheal intubation is that it is passed blindly and requires little skill to place. The EOA is usually used in the field.

ETCO₂ End-tidal carbon dioxide.

ET tube Endotracheal tube.

Extubation The removal of a tube from the trachea. It can be intentional, as at the end of anesthesia, or accidental in a semi-conscious patient.

In-line Neck Stabilization In trauma patients with suspected neck injuries, the neck is stabilized by an assistant during intubation to minimize potentiation of a neck injury

Intravenous Access Cannulae placed into the veins that allows administration of fluids and blood

Intubation Passage of a tracheal tube through the upper airway (nose or mouth) and larynx into the trachea.

Level One Trauma Anesthesia Simulation (LOTAS) Group A group of anesthesia care providers who have met regularly for six years to answer research questions from videotaped trauma anesthesia care

Manual Ventilation Ventilation achieved by compression of an anesthesia bag or self-inflating resuscitator bag

Mechanical Ventilator A device that is interfaced to the patient by means of a cuffed tracheal tube and allows positive pressure mechanical ventilation.

Muscle Paralysis Paralysis of neurotransmission by pharmacological use of drugs such as curare.

Oxygen Saturation (SpO₂) The percent O₂ saturation of hemoglobin in peripheral arterial blood. This value is monitored on a beat-by-beat basis by use of a pulse oximeter (see below).

Post-Trauma Questionnaire (PTQ) A research questionnaire completed by the anesthesia care provider(s) after each videotaped case

Pre-Oxygenation a technique to increase the O₂ reserves of a patient before induction of anesthesia. Breathing 100% O₂ through a close fitting face mask provides a reservoir of O₂ in the lungs to minimize the likelihood of the patient developing hypoxemia.

Pressure Support A form of mechanical ventilatory assistance that is activated by initiation of an inspiratory effort by the patient.

Pulse Oximeter Estimates the beat-to-beat O₂ saturation of peripheral arterial blood by a probe attached to the patient.

Resuscitator Bag A self inflating bag that is attached to a face mask or tracheal tube. Compression of the bag is used to provide oxygenation and ventilation.

SME Subject matter expert.

Tracheal Intubation Passage of a cuffed tracheal tube through the upper airway (nose or mouth) between the vocal cords and into the trachea.

Tracheal Tube Cuff An inflatable cuff that seals the airway to prevent aspiration and allow positive-pressure mechanical ventilation.

Ventilator Tubing Is the long flexible corrugated tubing used to make the connection between a patient's airway and a mechanical ventilator or anesthesia machine.